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KAME AREAS IN WESTERN NEW YORK SOUTH OF IRONDEQUOIT AND SODUS BAYS.

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INTRODUCTION.

Scope of the paper.—The bays of Sodus and Irondequoit are the extreme points in the great bight or landward curve in the south shore of Lake Ontario. They occupy the lowest points of two north and south depressions in the land surface, the effect, probably, of northward preglacial drainage, and locate the embouchure of the buried ancient channels.

During the recession of the great ice-sheet, the drainage of the comparatively stagnant Ontario lobe seems to have been largely determined, in this region, by these depressions, which evidently received a large share of the glacial drift. The Warren waters which continuously laved the receding ice front assisted in distributing and leveling the detritus, while its successor, Lake Iroquois, completed the work at a lower level. The extensive silt plains between Sodus Bay and lakes Seneca and Cayuga, and the Irondequoit terraces, are examples of such lake action.

The purpose of this paper is not to discuss the complicated and interesting sequence of geologic events in the region under consideration, but to describe certain massive deposits of sand and gravel apparently formed by the glacial drainage.

The term "kame" is here used in the sense which has become generally accepted, as designating deposits, chiefly sand and gravel, having a knob-and-basin topography, and formed at the margin or periphery of the ice-sheet. The term "esker" (osar, serpent-kame) is employed to denote distinct ridges, chiefly gravel, believed to have been deposited in the beds of subglacial streams, being phenomena of the radial drainage.

Three of the kame areas here described have been mentioned in former writings,[1] but a new explanation of their character and relations is here given. The Junius area is thought to be here

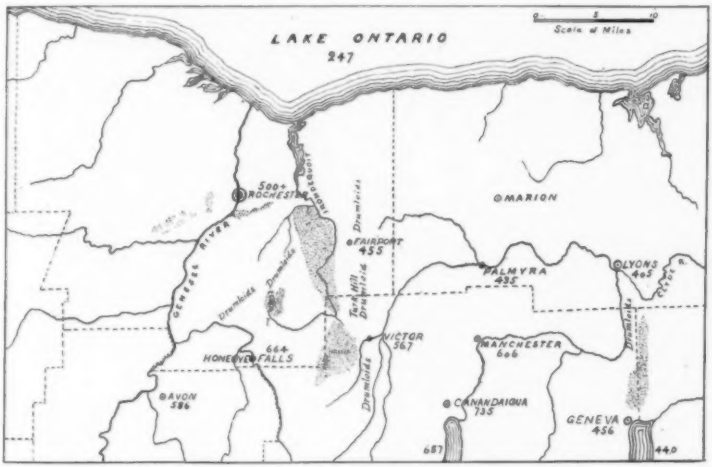
[1] The Glacial Geology of the Irondequoit Region, Charles R. Dryer. Am. Geol. Vol. V., p. 202, April, 1890.

Eskers near Rochester, N. Y. Warren Upham, Proc. Roch. Acad. Science. Vol. II., p. 181, January, 1893.

The Kame-Moraine at Rochester, N. Y., H. L. Fairchild. Am. Geol., Vol. XVI., p. 39, July, 1895.

mentioned for the first time in print. The Rochester kame-moraine need not be redescribed.

A comparison of the deposits will be made, and an attempt to show the relation of the areas to the glacial drainage and the larger topography, with a brief discussion of the problems involved. (See map, Fig. 1.)


LAKE ONTARIO
247
Scale of Miles
500+
ROCHESTER
GENESEE RIVER
Drumlins
Drumlins
Drumlins

Very extensive deposits of water-worn drift occur in some of the larger stream valleys. In the upper Genesee valley immense deposits of stratified drift are mingled with the till, and much of it inextricably confused with the local lake sediments and subsequent stream detritus. South of the divide between the south-flowing and north-flowing waters the valleys are choked with the glacial wreckage converted into stream drift. Upon the north or Ontario side of the divide the glacial drift of all kinds has been retained and used, by the combined action of streams and glacial lakes, to fill depressions and thus give the smooth surface and arable soil of all the region between Syracuse and Buffalo.

Lesser kame areas.—To enumerate the smaller deposits of gravel or sand left in billowy or mound-and-basin topography would be tedious, even if it were possible. Those immediately about Rochester have already been described by the writer.[1] Other limited deposits occur in many places. Sometimes they are barely distinguished from the general drift sheet. Sometimes they are indicated by a few low mounds projecting from the sheet of lake or stream drift which has almost buried them. The limitation of such lesser areas is indefinite, as they blend into the prevailing sand or silt plains. At low levels, without close examination, dune sands may be mistaken for kame deposits.

One area, which merits fuller description than can now be given, is found north and south of Palmyra, Wayne county. This deposit is not large in amount of material or extensive in area but is interesting on account of the development of typical eskers. It consists of an irregular, broken series of kame mounds and esker ridges lying in the north and south valleys between heavy drumloids, and extending northward from near Manchester, Ontario county, past Palmyra to beyond Marion, a distance of about twelve miles. North of Palmyra and north of Marion are well-developed, typical eskers. At the southern end of the system, near Manchester, the sand deposit is more extensive.

[1] The Kame-Moraine at Rochester, N. Y., H. L. FAIRCHILD. Am. Geol., Vol. XVI., p. 39, July, 1895.

This drainage system does not seem to have been determined by any large north and south depression or other controlling topographic features, and it is likely that other slender series of kames and eskers may be found in neighboring drumloidal valleys.

IRONDEQUOIT KAME AREA.

Location and extent.—One of the most extensive kame areas in western New York occupies the valley of Irondequoit creek, stretching from the deep depression of the bay or gorge past Pittsford to Fishers in the northwest corner of Ontario county. The extreme northern point of the deposit lies in a bend south of Allen creek, west of the Irondequoit gorge, where the main line of the New York Central Railroad has a large cut and excavation in the sand, which at that point makes a broad, high mass. This portion of the sand area and the western edge as far south as Pittsford are shown on the Rochester sheet of the New York topographic map. From the sand cut to within two miles of Fairport the railroad traverses the northern part of the kame area, as it swings southeast and east around the Irondequoit gorge past Penfield station and across the creek, a distance in curvature of four and one-half miles. The Auburn division of the same railroad passes along the western edge of the area, while the Erie canal crosses the area and the Irondequoit creek on a high embankment in line with an esker, as described by Dr. Dryer.[1]

The entire length of the area from Allen creek to Fishers is about nine miles. At the head of the Irondequoit gorge the breadth is about three miles, the area being almost entirely upon the west of Irondequoit creek, or between that creek and its tributary, Allen creek. We have no means of determining how much of the northern end of the area has been removed by the excavation of the Irondequoit gorge. South to Pittsford the remnant of the kame area rapidly narrows, and is restricted to the western edge near Pittsford, as the greater breadth on the eastern side has been leveled by the waters of lake Iroquois

[1] Am. Geol., Vol. V., p. 203.

and subsequent stream action. From Pittsford southeast to Fishers the kame deposits fill the valley to a width of about two and one-half miles.

South of Fishers is the extensive mass of kame drift described below as the Victor kame area. It might be regarded as a part of the Irondequoit area, and certainly it belongs to the same drainage system. Being separated, however, by an interval of low ground and drumloid till at Fishers and being so different in topography, with so great mass, it is found appropriate and convenient to describe it separately.

Topography, altitude, and drainage.—The base of the kame area rises toward the south, about 100 feet between Penfield station and Fishers. The northern and lower portion lies near the level of the ancient lake Iroquois (435 to 440 feet in this region) and a considerable portion was beneath the waters. At Cartersville, one and one-half miles southeast of Pittsford, the highest detrital plain cut out of the kame deposit has an altitude of 435 feet, but a discrimination has not yet been made positively between the lake terraces and the subsequent stream plains. The altitudes upon the main line of the New York Central Railroad across the sand area near the head of the Irondequoit gorge are as follows: Crossing of Allen creek, 420 feet; in the deep sand cut, 423; Penfield station, 417; crossing of Irondequoit creek, 407; Fairport, 455. The top of the broad sand hill near Allen creek, cut by the railroad, has an altitude of about 470 feet. The canal has but one "level" across the Irondequoit valley, of 461 feet. At Fishers the Auburn branch of the New York Central Railroad has an altitude of 510 feet, which is, however, within fifteen or twenty feet of the creek level, in the eroded channel. The Lehigh Valley Railroad crosses the valley and the western plain, being at Victor 567 feet, Fishers 557 feet, Mendon, 572 feet.

The surface configuration of the kame area is varied and difficult to describe briefly. Most of the surface north of Pittsford is billowy, low mounds of fine sand, perhaps largely the result of wind action. At the canal crossing the sand hills are lofty, of strong knob and basin topography and surround two

lakelets. From here south the drift forms massive hills, which culminate two miles north of Fishers, opposite Railroad Mills flag station. The creek at this point is crowded to the extreme western edge of the valley by the drift hills, which stretch eastward two miles to the Turk hill drumloid mass. The higher hill on the western side, known as Woolston hill, has been truncated or leveled by lake waters somewhat under 700 feet altitude. The same level is conspicuously shown upon other hills, east and south. The surface configuration is very striking, being partly morainic and partly erosional.

The drainage of the whole area is northward by Irondequoit creek.

Eskers.—Lying in the midst of the kame sands, nearly opposite Cartersville and north of Bushnells Basin, is a conspicuous esker which has been briefly described by Dr. Dryer. This esker first appears in a field of Mr. D. L. Guernsey (lot 21 of Pittsford town map), which is a fine adhesive or silty sand with rare stones and broad basins and kettles. In the southward sloping field the esker emerges from beneath the clayey sand at its full altitude as a ridge of gravel. For a distance of about one-fourth of a mile it extends nearly southeast, parallel with the Palmyra road; then turning more to the south it suddenly ends at the crossing of two highways. This break is perhaps the result of erosion. Some sixty or eighty rods southeastward the ridge is abruptly resumed at a gravel pit. At the top the gravel is dirty and unassorted; in the middle section is a heavy bed of clear cobble; while the bottom is finer gravel but without much stratification. Two-thirds of the cobble up to six inches in diameter is Medina sandstone.

From here southward the esker ridge is very distinct, somewhat curving, with irregular crest line. It is mostly 30 to 40 feet high, with steep slopes, 26° to 30°, and the crest in some places is clear sand. The highest section is 80 feet above the basin at its foot, with an eastern slope of 34°, in coarse gravel. From the high section it curves southeast and is lost in the artificial high embankment of the canal at the creek crossing,

beyond which it is probably buried under the lofty sand hills south of the creek. However, it can probably be identified south of the canal, at the south end of the canal embankment, in a mass of cemented, dark red Medina gravel which is similar in appearance to an exposure in the esker at the north end of the embankment. About 30 feet in thickness is shown of this cemented gravel, of which, by estimate, from one-half to three-fourths is red Medina. This occurs at the canal level, 461 feet. Similar dark red, cemented gravels occur at other localities; one and one-half miles south near the Rand powder mill; at Fishers station; in the sand cut near Allen creek at the extreme northwest point of the preserved kame area; also near the bottom of the Irondequoit gorge. It is suggested that these masses of cemented Medina gravels found in the distinct esker ridge and at different points in excavations northward and southward indicate the deposit of subglacial streams deriving their burden chiefly from the Ontario excavation in the Medina, which esker deposits have been mostly buried under the later sands deposited in front of the retreating ice.

Lakes.—South of Bushnells basin two lakelets exist, locally called "Bullhead pond" and "Lily pond." They are about one-fourth of a mile apart. The "Lily pond" is said to be shallow, the other deeper and more surrounded by sand hills. These are somewhat below the canal altitude 461 feet.

Another lakelet called "Crossman pond," or "Cedar pond," lies one-fourth mile north of Woolston hill, by the side of the Ketchum road. It has an area of about two acres, with a reported depth of 60 feet. The altitude is about 520 feet (aneroid).

Between Pittsford and Penfield are at least five pools and one swamp, lying in depressions in the billowy sand.

Composition and structure.—The surface of the northern portion of the area is chiefly a fine yellow sand. Below the Iroquois level this sand is much affected by the winds, and the billowy surface may be wholly due to æolian action.

The cutting by the railroad near Allen creek exposes about 70 feet of sand, inclosing a few lenses of gravel, and some angu-

lar material. A few bowlders occur, mainly Niagara. On the north side of the cut, twenty feet from the top, are heavy masses of cemented Medina gravel, about ten feet thick. These do not seem continuous. Another mass of similar gravel appears at the bottom of the excavation.

The top of the high mass is mostly fine sand but containing angular stones and a few bowlders. The surface from here south to Pittsford, two miles, and east to Penfield, one and one-half miles, is thrown into domes and basins. No gravels appear upon the surface north of the esker described above, although gravel is said to underlie the sand.

At Bushnells Basin and the canal crossing of Irondequoit creek the high hills are mainly the fine yellow sand, but heavy beds of gravel are worked near the canal, and cemented Medina gravels occur as described above.

The summit of the leveled Woolston hill is gravel, and heavy gravel is exposed in gullies on the slope. The hills of this culminating mass are reported as largely sand.

Till occurs in the base of the Woolston group, and on a terrace corresponding nearly with the plain stretching westward toward the Mendon hills. A land slide exposes 30 feet of till on this level, which is towards 100 feet above the creek, with a great thickness of sand beneath it. Till also occurs at a higher level on the north side of the Woolston hill. A conspicuous hill south of village of Fishers and another smaller one southeast are true drumlins.

The depth of the sand upon the borders of the northern part of the area cannot be great. Toward Penfield the water pools indicate a substratum of rock or till at altitude of about the Iroquois level. Through the midst of the area there exists a buried ancient valley.

Surrounding features.—The kame deposit lies upon the glacial filling of the ancient valley, lapping upon the drumloid till either side. Being wholly in a north-sloping valley and at a low altitude, the lowest northern part of the deposit was at first leveled by the waters of lake Iroquois, while the whole area has been

subjected to the valley drainage. Doubtless a considerable part of the original mass has been swept into the Irondequoit bay depression. The details of this history, as connected with Irondequoit bay, will be reserved for another paper.

There are no important morainal features upon either side of the kame area. West of the southern part of the area, at a distance of five miles, is the large, isolated group of the Mendon kame hills, with a plain intervening; otherwise the east and the west boundaries are drumloid. South is the enormous deposit of gravel forming the Hopper and Fort hill groups of Victor, which are really the antecedent part of the Irondequoit kame system. At Victor is a break in the Turk hill drumloid range, through which the Lehigh Valley and the Central railroads find passage.

VICTOR KAME AREA.

Location and extent.—The most massive kame hills in the region, and probably in all western New York, are in the southwestern part of the town of Victor, Ontario county, extending into the towns of East and West Bloomfield and into the southeast corner of Mendon, Monroe county. (See Fig. 2.) They cover an area of some ten square miles and attain in the "Hopper" hills the lofty altitude of over 1100 feet. The area is elongated north and south, the northern apex being at Fishers station the Auburn branch of the New York Central Railroad, and the southern end forming a narrow belt terminating two miles south of Millers Corners station, on the Batavia and Canandaigua branch of the same railroad. The total length is about seven miles. The greatest breadth is about three miles, where the group culminates in the remarkably bold ridges northeast of Millers Corners.

Topography, altitude and drainage.—The higher kame hills of this area have a very remarkable topographic relief. The culminating mass is locally known as the "Hopper" hills, which lie immediately north and northeast of Millers Corners, upon the north and south line between Monroe and Ontario counties. This is a lofty, ridge-like mass lifted high above the surrounding

kames and conspicuous over a wide territory. (See Fig. 3.) The mass is irregular in form, but with the longer axis north and south, or east of south, and a length of over one mile. Upon all sides

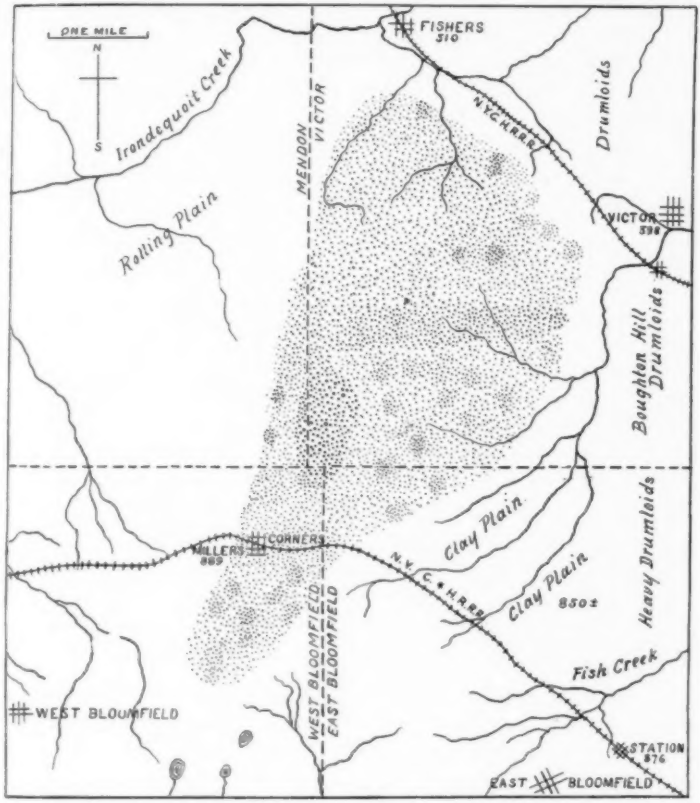


Fig. 2. Map of Victor Kame Area.
Figures indicate altitude above mean tide.

except the south it rises steeply 400 feet, attaining an altitude of 1131 feet (aneroid) above sea level, overtopping everything in western New York north of the Devonian plateau. Superficially the

mass is entirely water-laid drift, mainly gravel, and there is slight evidence of clay or till. No deep exposures have been made, and there are no land-slides, as occur upon neighboring steep kames where clay exists. The people in the vicinity report no clay or "heavy soil." The cultivated fields upon the summit show only sand and rather fine, well-rounded gravel. However it is possible that the water-laid drift is only a veneer upon a mass of till.

Southward the Hopper mass is continued in the belt of kame hills of lesser height stretching past Millers Corners. These have an altitude of 900 to 1000 feet, which height is preserved until they terminate against the rising ground to the south.

With only a fringe of comparatively low knolls, the western slope of the Hopper range falls rapidly to the rolling clay plain which declines westward toward Mendon and Honeoye Falls.

Upon the north and northeast a narrow gulf separates the mass from the western end of the Fort hill kame range. East and southeast a narrow valley intervenes between the Hopper range and the lower kames. The latter have an average altitude of 850 to 900 feet, being mostly water-leveled, and blend into a a till or clay plain of the same altitude, flanking the heavy drumloid ridges eastward. These drumloids are in line south from Victor, the northern one being known as "Boughton" hill.

North of the Hopper range and separated by a narrow valley is a broad, less elevated series which we will name the "Fort" hill range. This name is locally given to the conspicuous, abrupt plateau at the eastern end of the range, about two miles from Victor, which is historically famous as the site of a stronghold and of the defeat of the Seneca Indians by Denonville, in 1687. This range has been mostly truncated by static waters, the plateaus being 850–865 feet altitude and the highest summit 885 feet (aneroid). The breadth is about one-half mile and the length about two miles. The trend is north of west, the western end being separated from the northern end of the Hopper range by only a narrow gulf.

Northward toward Fishers the hills seem small by comparison

with the Hopper and Fort hill ranges, but are really of respectable size, somewhat mound-like and billowy in contour, closely huddled together, and diminishing toward the northern end of the area.

The surface of the entire area is knob and basin topography. Broad basins and deep kettles occur even to near the top of the

Fig. 3. VICTOR KAMES.

View from near Tobin's Corners, looking west 15° north, "Hopper" Hills in background. The point of view is upon the upper erosion plane of Warren waters, which also shows in distance upon right.

Hopper range. This topography has lost, however, some expression by the leveling effect of the Warren waters. Between 850 and 875 feet altitude the kames are strongly terraced or truncated, this plane being one of the conspicuous features of the region. A few summits in the southeastern part of the area, and one summit of the Fort hill range, have escaped the leveling action of

the static water. Another water-plane, toward 700 feet altitude, is less evident.

The drainage is west and north into Irondequoit creek and north by Great brook, the latter flowing upon the west side of the Boughton drumloid and joining Mud creek east of Victor.

Few water-pools worth mentioning occur. One pool lies in a deep basin between the western ends of the Hopper and Fort Hill ranges, back of the house of Mr. Covill. The large basins seem to be of pervious materials and far above the till or rock floor. Good kettles holding water except in dry seasons occur north of the Fort hill range.

Eskers probably do not occur in this area. If any exist they are in the northern part of the area east of the Fishers and Millers Corners road.

Composition and structure.—Till is found in the knolls near Millers Corners. The top of one hill, a mile northeast and with altitude of about 900 feet, seems to be wholly till, with bowlders. One-fourth mile west of the station the railroad makes a cutting in till which is probably drumloidal. Some of the slopes and summits are coarse sand, but the great bulk of the higher ranges is gravel. Fort hill is capped with sand, but the rest of the range is mostly gravel. Less sand is seen upon the summit of the Hopper range, the highest points being fine gravel. The composition of this range has been described above. The hills south of Millers Corners contain much gravel and some heavy beds of very round cobble. The bulk of the northern, constricted area toward Fishers seems to be sand, but Dr. Dryer states that there is much till in the knolls and plateau lying north of the Fort hill range.

Stones and cobbles are found in the sand at various elevations. The foundation of the southern part of the area is Corniferous limestone and the characteristic chert is found upon the summits of the Hopper range. The northern edge of the Corniferous is traced near Victor.[1] Large bowlders of crystallines, Medina and Corniferous are seen along the highway between

[1] Economic and Geologic Map of the State of New York, by F. J. H. Merrill, 1895.

Fishers and Millers Corners, especially near Millers Corners. A large proportion of the gravel, even to the Hopper summits, is Medina.

Surrounding features.—This kame area evidently belongs to the same glacial drainage as the Irondequoit kame area. The reasons for treating it as a separate area have been given above.

The area is bounded on the northeast by the northwest-southeast valley reaching from Fishers to Victor. Upon the east it is bounded by the Boughton hill drumloid which runs directly south from Victor village and which, notwithstanding the break at Victor, may be regarded as the southern continuation of the Turk hill mass, with which it is in line. Southeastward the kames are lost in a smooth plain of till or clay, as mentioned above, which joins a marsh north of East Bloomfield and is the level of the upper erosion plane of Warren waters. As casually seen in exposure by the roadside, this clay is of reddish color, with only small but striated stones. The streams have excavated narrow channels 40 to 60 feet deep through this plain, and are possibly on rock. Southward is high ground with a drumloidal surface, the northern spurs of the Devonian plateau.

Westward is a low silt plain, evidently deposited as a lake floor, and which may be regarded as an overwash from both the Victor and Irondequoit kames. This plain declines west toward the Honeoye creek and north toward the Irondequoit creek, with an altitude averaging about 600 feet.

It will thus be seen that the Victor kame area lies in an angle or embayment of the Warren shore line, opening toward the northwest. Northwest a few isolated mounds of sand rise out of the low silt plain, the only phenomena connecting this kame area with the Mendon kame area. Neither westward nor eastward are there any good evidences of morainal till.

In Professor Chamberlin's description of the terminal moraine in New York[1] this Victor kame group was united with the southern part of the Turk hill mass and regarded as an intermediate

[1] THOMAS C. CHAMBERLIN, Terminal Moraine of the Second Glacial Epoch. Third Ann. Rep. U. S. Geol. Surv., p. 353, and Plate XXXIII.

or interlobate moraine. The same view was subsequently held by Dr. Dryer.[1]

By referring to Professor Chamberlin's description it will be seen that he had serious doubt as to the correctness of the diagnosis. He closes the brief description with the following: ". . . . for the glacial movements on either side of the moraine appear to have been southerly, as judged from the prevalent trend of adjacent drift ridges, and therefore essentially parallel to the moraine, instead of being at right angles to it, as in the case of a true intermediate moraine."

The Turk hill body of drift is somewhat anomalous but is surely drumloidal in general character. The northern end, at Fairport, is divided into a few large ridges, which blend together southward and constitute a broad, plateau-like mass, over 900 feet in altitude. The western boundary is a fairly continuous slope, with considerable water-laid drift banked against it, and the Irondequoit kame area flanking it opposite Fishers. The eastern side is more irregular and the depressions have been largely filled with water drift. The southern declining half of the drift body is also very gravelly and of irregular surface. East of the high mass the drumloids are numerous but smaller. Much of the morainic appearance on the slopes and on the southern half of the Turk hill mass is certainly due to sub-aërial erosion. The drainage is all free. There are said to be no lakes, no swamps, and no sinks or kettles.

Upon Professor Chamberlin's map (Plate XXXIII. of the paper referred to) this supposed moraine is isolated, and with its north and south trend is quite inexplicable. It is the only isolated moraine depicted in New York north of the great east-and-west terminal moraine, and its elimination from the map simplifies the glacial phenomena of the region.

MENDON KAME AREA.

Location and extent.—A remarkable accumulation of kame sands and gravel occurs in the southeastern part of Monroe

[1] See former reference.

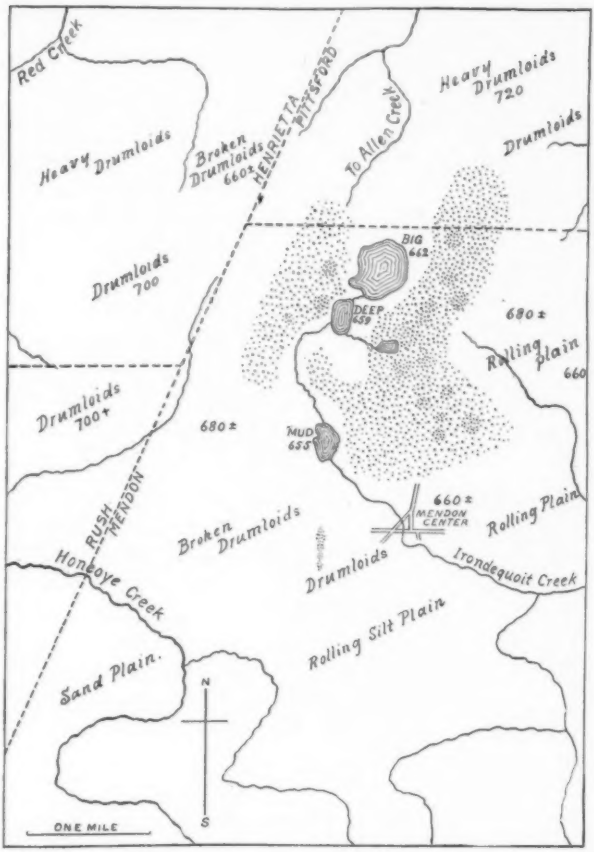


Fig. 4. Map of Mendon Kame Area.
Figures indicate altitude above mean tide.

county in the town of Mendon. The deposit has been referred to in the papers by the writer and by Dr. Dryer, but they deserve a fuller description.

The hills which constitute the heart of the kame area lie either side of the Mendon ponds. They may be said to form two

series of hills and knolls having a general direction of S. 30° W. with a low valley between holding the five ponds. (See Fig. 4.) The heavier group lies on the east side of the valley, extending between two north and south roads a distance of about two and one-half miles, with a breadth of three-fourths of a mile. The western group lies between the ponds and a north and south road and is only about one-third the area of the eastern group. The southern limits are not definite but shade into the silt-covered drumloids.

Southward, past Mendon Center, the general contour of the surface is drumloidal, but there seems to be a deposit of silt or sand over the surface and filling the hollows. This area of silt is indefinite and is intersected by the excavation of the Honeoye creek valley. Beyond this excavation a sand plain forms a conspicuous level, locally known as the "Mendon plains." This lies southwest of Rochester Junction on the Lehigh Valley Railroad and extends to Sheldon Corners.

Eskers.—Through the midst of the eastern high track there winds an esker ridge. This is not conspicuous, but from some points of view the knolls blend so as to form a very evident eskerine. (See Fig. 5.)

One mile south of the kame area occurs a singular group of knolls that must be regarded as an esker. This lies one-half mile south of Mud pond and three-fourths of a mile west of Mendon Center. The north end of the esker is cut by the east and west highway. This esker consists of four connected knolls, in a north and south line, making altogether a length of about one-eighth of a mile. The local name of the knolls is the "Dumpling hills." The summits and slopes of the ridge and the road cutting show only a fine, stiff or silty sand, similar to much of the surface of the region southward. A few stones were observed in the sand. The esker is thirty to fifty feet high but surmounting a ridge, probably drumloid, it is conspicuous over considerable area. Its altitude is 762 feet (aneroid). The sides of the esker are very steep and ridges of sand stretch away from it at right angles.

Topography, altitude and drainage.—The Rochester sheet of the New York topographic map includes the kame area, in twenty-foot contours, and to this map the writer is indebted for the altitudes. The swamp area surrounding the ponds has an altitude at the north end of 665 feet and at the south end of 655 feet. The highest peaks of the kame hills, in the eastern tract, are

Fig. 5. MENDON KAMES.
View looking southwest over "Harris" lake. Eskerine at right.

given contours of 840 feet. These are 100 feet higher than the highest drumloids in the surrounding region. This altitude of the sand hills is a striking feature. Eight miles southeast are the Victor kame hills of much greater height. Higher ground is found in about ten miles southward on the Hamilton-Chemung plateau. North of this plateau of the "Finger lakes" region there is in all of western New York only one area, excepting the Victor hills, surpassing in height the Mendon hills; this is the drumloid mass of the Turk hill group, seven miles east,

which is about eighty feet higher. The most northern point of the high plateau is at Batavia, on nearly the same parallel as the Mud pond, where the drumloidal and morainic drift capping is something over 900 feet.

While the summits of the kame hills are 100 feet above the surrounding drumloids the enclosed swamp valley is nearly 100 feet lower than the drumloid region. It has not been determined whether the swamp is floored by rock or by impervious drift.

The topography of the hills is of pronounced knob and basin type and strikingly in contrast with the neighboring drumloids. (See Fig. 6.) They are conical, mammillary, billowy, enclosing numerous basins and deep kettles. The hills have nearly escaped the leveling action of the Warren waters, the summits lying between the two erosion planes. However, the lower, 700 feet, plane shows upon the western hills.

The drainage from the ponds and enclosed valley is immediately southward, forming the head of the Irondequoit creek. After passing Mendon Center the stream swings eastward to Fishers and then northward to Irondequoit bay. From the borders of the kame area the drainage is radial in all directions.

The altitude of the southern part of the overwash sand and silt is about 600 to 610 feet (aneroid).

Lakes.—The location, drainage and relative size of the four lakes are shown in the accompanying sketch. The "Big pond" lying most northerly and the head of drainage, has an area of about 100 acres, and a depth of only about eight feet. The "Harris pond" lies nearly surrounded by the heavy drift on the east side of the valley. It is only a few acres in extent but is said to have a depth of twenty-four feet. "Deep pond" is mostly shallow but is said to be thirty-four feet at the deepest place. "Big pond" and "Mud pond" are shallow. The margins of the lakes are mostly swampy, but much of the valley bottom between the lakes is tilled land.

Composition and structure.—The kame hills are mostly pasture land or under cultivation. Very few exposures have been made

and these show mainly imperfectly assorted gravels. The tops and slopes of the hills are frequently of material so fine and adhesive as to be clayey. Till is found in the high knolls north and south of the Harris pond and probably occurs elsewhere. In the valley near the Deep pond lies one small but very distinct elongated drumlin. No exposures are seen of fine, clear sand

Fig. 6. MENDON KAMES.
View looking west of north over "Big" and "Deep" lakes.

blown about by the winds as in the Irondequoit and Junius areas and other sand areas near Rochester. The materials as a whole are varied, but the finer are generally rather adhesive or silty.

Some gravel pits in the borders of kame area show materials one-half Medina. Large bowlders of crystalline rock and rarer blocks of Niagara limestone occur throughout the region. In the middle valley and upon the southern borders of the area frequent cobblestone fences, one-half Medina, indicate considerable

coarse material upon the surface. Two huge Niagara blocks were seen on a gravel knoll at an altitude of 720 feet. A well upon one of the knolls in the southern part of the eastern section is said to have penetrated 130 (?) feet of clear sand.

Relationship to surrounding features.—An examination of the Rochester sheet of the New York topographic map will give a general view of the surface and surroundings of the kame area. It should first be noted that it lies in a drumloid area of high altitude, and a trifle west of south of the Irondequoit bay depression. The tract northward between the kame hills and Pittsford, four miles, is strongly drumloidal. Upon the west the country is distinctly but brokenly drumloidal and for two miles is not so strongly ridged. The twenty-foot contours of the topographic map do not anywhere fully indicate the drumloidal character of the surface. Southwestward the surface is drumloidal to the Corniferous escarpment, the overwash partially burying the lesser inequalities. Immediately south of the kame hills, at the village of Mendon Center, are distinct drumloids, and others apparently occur upon the southeast border. Eastward and southeastward the country is comparatively open and rolling for several miles, to the Victor kame hills. Immediately east of the middle of the kame area the ridges are quite wanting, the highest contour being 680 feet.

Concerning the rock floor or base of the region little is known. Upon the Howard farm, on the extreme western edge of the kame area, it is said that a well, starting on the 700-foot contour, was driven 130 or 140 feet without reaching bed rock. The well above referred to started at an altitude of about 680 feet and found no rock at depth considerably over 100 feet. In the southern part of the sand plains, on the farm of Mr. Judson F. Sheldon, rock is said to have been found at a depth of 69 feet. The plain at this point is near 600 feet altitude.

Eastward or westward of the kame hills there is but the slightest suggestion of a moraine. One and one-half miles northward of the Big pond a slightly morainic surface is shown among the drumloids, also two miles west, along the Lehigh Valley Railroad.

JUNIUS KAME AREA.

Location and extent.—A large and interesting kame area is

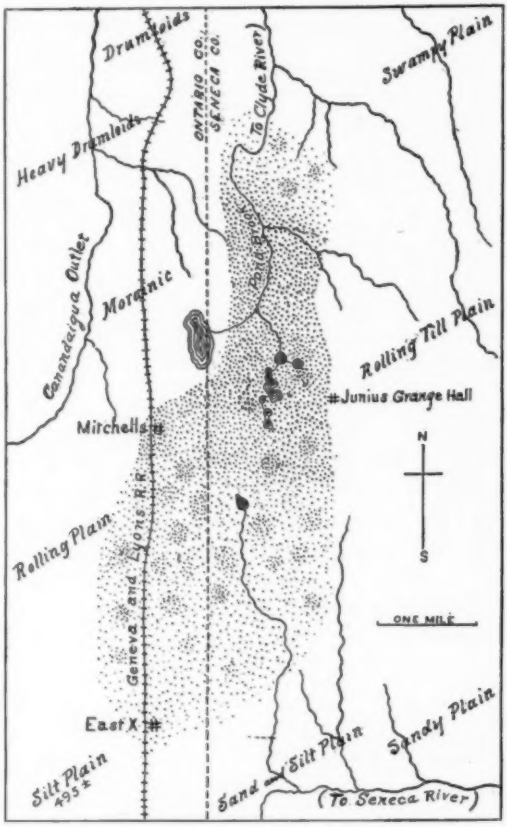


Fig. 7. MAP OF JUNIUS KAME AREA.
Figures indicate altitude above mean tide.

found north of Seneca lake in the town of Junius, in the north western edge of Seneca county and extending over the line into the town of Phelps, Ontario county. (See Fig. 7.) It lies mid-

way between Geneva and Lyons, but east of the meridian line, and constitutes the highest ground upon its meridian between lakes Ontario and Seneca. The boundaries of the sand areas are indefinite but the northern limit seems to be about one-half mile north of Bisch's sawmill or five miles in a direct line from Lyons. The heart of the area is the group of knolls surrounding the Junius ponds. Southward the knolly area broadens, east and west, and blends into the wide silt plain which extends to Seneca lake.

The width of the kame area on the "state road," which passes between the ponds and through the heart of the area, is about one and one-half miles. Junius Grange Hall is just at the eastern limit of the sand, and the western limit is beyond Mitchell's station (West Junius P. O.) on the Geneva and Lyons R. R. North from this station the railroad passes a mile west of the sand area; southward the railroad lies in the sand to beyond East X station, within three miles of Geneva. The length from Bisch's Mill to East X is about six miles.

Topography, altitude and drainage.—It is said that the surveys for the Geneva and Lyons Railroad made the height of the South pond 34 feet above Seneca lake. This is probably not far from correct, and would make the altitude 474 feet above tide. The South pond is about 13 feet higher than the other ponds. All the ponds in the heart of the area are drained northward by one brook into the Clyde river, with a fall of about 80 feet. The southern part of the area, including the swamp and the Lynch pond, is drained southward into Seneca river.

The topographic relief of the kame area is not remarkable. The higher knolls rise some 70 or 80 feet above the ponds, giving an extreme altitude of perhaps 550 feet above tide. The surface in the region of the ponds is decidedly hilly, but southward it would be better described as "billowy."

Lakes.—The lakes are notable for their reported depth as compared with their small area. The largest one, "North pond," with an area of about twenty acres, is said to be 62 feet deep. The others are reported to be of great depth. "South pond,"

the head of drainage, has a surface of about nine acres. The smallest, lying between North and South ponds, has an expanse of less than an acre. The two lakelets furthest north are called "Newton ponds." Only five lakes are here recognized, although the group is sometimes called the "Seven ponds." "Burnett's pond," which lies west of the sand area and is much larger and more shallow, is not here regarded as a member of the kame group. About one mile south is another lakelet in a large swamp.

The five kame ponds are said to retain their level in the driest seasons. Without any surface stream supply they must derive their waters from a large basin of sands enclosed in impervious drift.

Composition and structure.—The exposed material of the kame area is mainly fine yellow sand. A few gravel exposures are met with in the neighborhood of the ponds. East of Mr. J. C. Vandemark's residence a dark cemented gravel occurs in the crest of a knoll. The matrix is a dark, reddish, coarse sand. Of the gravel not over one-quarter is Medina, the remainder being a mixture of many hard rocks from the northern terranes. Some clay or stiff soil is said to occur on the tops of the knolls. Stones and bowlders are found at all heights in the sands. Southeast toward Waterloo and south toward Geneva the billowy yellow sands terminate in the silts of a broad plain, with occasional low, sandy knolls.

Surrounding features.—East and south of the kame area is the somewhat lower silt plain which extends from Geneva and Waterloo northward past Clyde to Sodus bay. The surface of the ground bordering north and west is boldly drumloidal, but northward it is slightly lower in altitude. West of the north end and heart of the kame area is a significant morainic deposit. It is best described as a morainic filling of the north and south valleys between the drumloid ridges. Part of the irregularity may be due to the east and west outcrops of harder strata of the upper Salina. This morainic surface extends along the Geneva and Lyons highway from about one mile south of Alloway to West

Junius post office (Mitchell's station). It is regarded as marking the edge of the ice-sheet during the accumulation of the larger kame hills by the concentrated drainage.

COMPARISON OF THE KAME AREAS.

It will be instructive to briefly compare the principal features of the four large areas described above, including in this comparison the Rochester kame-moraine and some lesser areas.

The Irondequoit, Victor and Mendon areas are apparently the result of heavy drainage from the wasting ice-sheet, concentrated along the Irondequoit depression. The neighboring deposits of the Rochester kame-moraine and other lesser deposits southwest and west of Rochester have an uncertain, if any, relation to the Irondequoit drainage. The Junius area is in a separate and distinct glacial drainage system, belonging to the Sodus depression.

The Irondequoit area is singular in one respect; it rests in the lowest channel of the depression and partly below the level of Iroquois waters. The other areas are upon relatively high ground and constitute the highest points of land in their vicinities and upon their respective meridians, north of the Devonian plateau.

All the areas are alike in being located in the basin of lake Warren. Excepting the Junius area they are also alike in bearing evidence in the beautifully terraced and truncated sand hills of their accumulation beneath the Warren waters. Two strongly developed water levels are conspicuous; the higher between 850 and 900 feet, the lower about 700 feet above tide. The Junius area lies at so low an altitude that the hills have escaped the leveling action of any long pause of the Warren waters, their summits being much below 600 feet.

The areas are alike in having an overwash sand or silt plain to the southward.

The basement terranes are as follows: The Rochester kame-moraine lies upon the southern edge of the Niagara limestone. The Irondequoit stretches across the whole breadth of the Salina. The Mendon and Junius areas lie upon the Salina but near its southern limit. The Victor area lies chiefly upon the Corniferous

limestone. The composition of the three southernmost areas seems to partake somewhat of the clayey nature of the Salina strata. The Mendon, the Victor, and the Irondequoit sands, above the Iroquois level, are generally more coherent and argillaceous than the lighter sands of the Pinnacle and Chili hills near Rochester. This, however, may not be of great importance, especially since the Junius sands are also comparatively light.

The four areas lie in the midst of drumloid ridges which certainly antedate the kame deposits that partially overlie them.

Only the Rochester area has any clear connection with an extended frontal moraine. The morainic surface immediately west of the Junius hills is significant but not sufficiently clear or extensive to be important in this connection. It should be said, however, that in the drumloidal region bordering these kames an amount of morainal material even surpassing that in the moraine west of Rochester would scarcely be noticeable.

The break at Fishers may possibly be partly the scouring effects of currents during the lowering of lake Warren, but not entirely, and the cessation at this point of the process of such heavy drainage accumulation would seem to render probable the accumulation at some other point on the ice-front, east or west. For this reason the suggestion is made that the Mendon area may have been formed by the temporary westward diversion of the main Irondequoit drainage; that is, the Mendon water deposits may represent the gap between the Victor and the Irondequoit deposits. The center of the Mendon area is about five miles from Fishers, which lies in the break between the other two areas, and it has the proper position transversely to the drainage line.

DISCUSSION OF PROBLEMS.

The precise manner of formation of the kame hills is the most obtrusive question. Two elements may be considered in this connection, the composition of the kames, and their altitude and location. In composition the red Medina waste plays the

conspicuous rôle. In the Irondequoit esker it is 50 to 75 per cent. of the whole mass. The kames contain somewhat less waste of the Medina, although the red color is usually pronounced even upon the highest summits. The Medina is the lowest terrane of the region, the top being only about 100 feet above Lake Ontario. In the Victor subaqueous kames, leaving the lofty Hopper range out of account, Medina gravel has been lifted towards 500 feet. Of this height not over 200 feet is due to the southward rise of the rock base, which leaves nearly 300 feet of actual lifting of the gravel. The distance from the Victor hills to the nearest Medina exposure, at the head of the Irondequoit gorge, is 12 miles. Another example is more striking. The Corniferous chert also occurs upon the tops of the Victor hills. The limestone is supposed to underlie the hills, but it cannot extend farther north at present than three or four miles. Within that distance the Corniferous has been lifted about 300 feet. Flotation by ice in lake waters might explain the presence of fragments of chert on these summits, but the Medina gravel which forms a constituent part of the hill summits cannot be so accounted for. The overriding of the gravel deposits by the readvancing ice will probably account for the till upon the higher kame summits, as it will for the angular blocks of Niagara limestone upon the summit of the Pinnacle, and for the till on Cobb's hill of the Rochester kame-moraine, but the areas here described give no evidence of extensive burial under glacial ice.

The summits of the Hopper ridge are about 250 feet above the upper lake terraces. It seems possible that some part of this remarkable elevation of the water drift upon this ridge may be due to a pushing by the ice in a slight readvance. The direction and form of this high ridge, however, are not entirely consonant with its being a pushed moraine. The interior structure of the hills is unknown. This explanation, a pushing by the ice, applies in part to the Rochester kame-moraine. Possibly it may partially apply in the case of the Fort hill range lying immediately north of the Hopper range, but it would

scarcely be suggested by the form of the hills in either of the other kame areas. It should be noted here that the directions of the Hopper and Fort hill ranges are nearly at right angles to each other.

There can be no doubt that the greater part of the material of all the groups has been derived from the Ontario excavation and rock degradation upon the north, and has been carried southward up hill. It has been lifted hundreds of feet by either ice or water, or both combined. Upward currents probably do not exist in the body of the ice-sheet sufficient to lift the subglacial débris to such a height in so short a distance. Indeed, the material, if taken from the ground moraine, would require to be lifted far above its present height, as the fully rounded gravel and the large proportion of sand represent the wear of a considerable journey by stream transportation.

The theory advanced by Professor Shaler[1] several years ago seems the most acceptable. In some manner the lifting of the gravel and sands may have been done by forceful upward currents of water at the ice-front, impelled by the hydraulic pressure of water in the lofty ice-sheet to the northward. The kame deposits under discussion were doubtless formed in the waters of lake Warren, along a belt where the deep static waters opposed the detritus-burdened, glacial torrents. The buoyant effort of the static water probably kept the ice-front comparatively steep or high. The heavier glacial streams would probably cause deep reëntrant angles in the ice-front, or even canon-like indentations, which would be choked by the piling of the detritus until a balance was established between the height of the detrital dam and the lifting power of the stream. The full analysis of the interaction of the three agencies, the ice-sheet, the subglacial streams, and the static water, would be exceedingly instructive in this study.

Professor Shaler supposed the Martha's Vineyard kames to

[1] On the Origin of Kames. Proc. Boston Soc. Nat. Hist. Vol. XXIII., 1884, pp. 36-44. Geology of Martha's Vineyard. Seventh Ann. Rep. U. S. Geol. Sur., 1885-6, pp. 314-322.

have been formed beneath sea-water. The static water in the cases under discussion was fresh water and would oppose less resistance to the glacial streams.

The chief and perhaps fatal objection to this explanation is the extreme height of the Hopper range, which is 250 feet over the highest water-level, but there is so much uncertainty concerning the internal composition of the Hopper mass that it is an unsafe basis in this argument.

This discussion has a direct bearing upon the matter of glacial drainage in another aspect. To deny the possibility of ice-dams, or the capacity of glacial ice to serve as a barrier to deep water, requires evidently interglacial or subglacial drainage to the sea in the case of the Ontario glacier. The topography of the land surface is such that during the melting toward the northeast of the Adirondack-Ontario ice-sheet the resulting waters must either have been ponded in front of the ice or have been suffered to escape beneath the ice to the sea by the St. Lawrence or the Mohawk depressions. The latter alternative means northward drainage. As a matter of evident fact these kame areas consist of matter derived from terranes lying upon the north, and as evidently were produced by water currents from the north. The waters flowed from the ice-sheet not into the ice-sheet.

The fact of static waters over the region is clearly shown by the two conspicuous erosion planes upon the kame hills, as already described. The suggestion of marine submergence is not entertained.

The general trend of the kame areas southwestward may have been due to the prevailing direction of the glacial movement.

The glacial débris above the ground moraine throughout this region seems to have been deposited chiefly as water-laid drift. The kame areas stand apart, without morainic connections, and terminal or frontal till moraines are no more than barely observable. The causation is probably complex. Rapid ice retreat; action of the lake waters preventing considerable local accumu-

lations of morainal till, or subsequently either dispersing or burying them; and the fact of the heavy glacial drainage, occur to mind as possible causes. Another important fact is that the bulk of the ground moraine had been left as heavy drumloid ridges.

The relation of the drumloid and the kame deposits are such as to clearly indicate the later deposition of the kames. For many reasons the writer has no doubt of the subglacial origin of the drumlins and drumloids of western New York, which are here regarded as a part of the ground moraine.

H. L. FAIRCHILD.

A PRE-TERTIARY NEPHELINE-BEARING ROCK.

WHILE engaged in a petrographical study of the glacial drift bowlders in the neighborhood of Columbus, Ohio, with a view to ascertaining their possible source, a bowlder of unusual interest was noted. It is related to types which have only recently been described in this country. The rarity and interest of the type and the hope of making possible its future identification with an occurrence found in place seems to justify a special description of this bowlder. Only a single specimen was found. This was about a foot and a half in diameter, with a surface weathering conspicuously rough and brown.

Macroscopical characters.—On the fresh fracture the rock shows a dark gray, compact, aphanitic groundmass, thickly studded with lath-shaped or, more rarely, tabular crystals of a triclinic feldspar. These phenocrysts have an average length of half an inch, but may be more than twice that length. They are white to colorless and translucent, with a pearly luster, and show the striations due to polysynthetic twinning. Upon the weathered surface of the rock they stand out in marked relief and are an opaque white, with a chalky texture.

Less conspicuous, but distributed in great abundance through the rock, are groups of broadly rectangular, or hexagonal, white or nearly colorless crystals. These crystals do not exceed two millimeters in diameter and are uniformly and clearly distinguished from the feldspar by their shape and size. They are not in marked relief on the weathered surface, but are conspicuous as small, squarish, chalky white spots.

A dark-colored, ferromagnesian constituent, presumably augite, is present less conspicuously, as a phenocryst. Magnetite can also be detected, and doubtfully olivine.

Microscopical characters.—The microscope shows the essential

constituents of the rock to be plagioclase, nepheline, augite and hornblende. As accessory constituents, always present in some amount, are olivine biotite, apatite and magnetite. As secondary constituents are a zeolite, muscovite, kaolin, calcite and uralite. The rock is comparatively fresh and possesses a panidiomorphic holocrystalline structure. Secondary structures due to pressure are not manifest.

Plagioclase.—The feldspar is fresh, idiomorphic and polysynthetically twinned. The twinning lamellæ are indistinct and irregular. It is comparatively free from inclusions which, when present, are apatite, augite and hornblende crystals and microlites. Some of the feldspar was isolated and its specific gravity tested by the Thoulet solution. It proved to be 2.642 indicating a variety of the oligoclase-albite series. Feldspar of the second generation occurs in the groundmass, of which it constitutes the major part. It is broadly lath-shaped and does not show repeated twinning, but is, in many instances, twinned according to the Carlsbad law. Besides occurring in lath-shaped crystals it acts as a cementing material for the minerals of the groundmass. The presence of muscovite is conspicuous as an alteration product. This alteration product, the high alkali percentage of the groundmass and the optical properties, indicate that the feldspar of the groundmass belongs at the more acid end of the series, probably orthoclase in part.

Nepheline.—The groups of colorless, broadly prismatic or hexagonal crystals observed in the hand specimen prove to be nepheline. The hexagonal sections show the broad uniaxial cross and negative double-refraction of nepheline. The prismatic sections show parallel extinction, a weak double refraction, and two rectangular cleavages. The crystals contain as inclusions apatite and augite. The former is abundant throughout the sections in idiomorphic crystals, and is readily distinguished from the nepheline by its higher index of refraction. The nepheline is frequently quite fresh but sometimes shows alteration into a radiating zeolite which possesses the optical properties of natrolite. The alteration begins on the outer edge and the nepheline

crystals are, in many instances, bordered with a narrow edge of radiating zeolite needles. In association with this alteration is an alteration to colorless, brilliantly polarizing muscovite. The nepheline also weathers into an irresolvable, granular, whitish, dimly polarizing substance which may be kaolin. Some of the powdered rock, from which was excluded all phenocrysts except nepheline, was tested for the alkalies. Three-tenths of one gram of this powder, of which about one-half was nepheline, showed an alkali content as follows: soda, 8.32 per cent.; potash, 7.08 per cent. A sample of the powdered nepheline, very nearly pure, gave soda, 7.70 per cent.; potash, 3.74 per cent. The presence of a potash feldspar, as an orthoclase, in the groundmass would account for the high potash percentage in the first sample.

Augite.—Augite occurs in unmistakable, idiomorphic crystals of a violet color. There is a manifest pleochroism. $\mathfrak{c}$ = violet. $\mathfrak{a}$ = green. The crystals are frequently bounded by the prismatic and pinacoidal planes, giving octagonal cross-sections. Twinning parallel to the orthopinacoid is present, and zonal structure is not uncommon. Inclusions of apatite and magnetite are abundant. More rarely are found inclusions of olivine. The peripheries of the crystals show a narrow border of alteration to a uralitic, or to a reddish brown, hornblende.

Hornblende.—This mineral occurs both as phenocrysts and as a constituent of the groundmass. In the former case it is a rich red brown, with marked pleochroism and absorption. $\mathfrak{c}$ = reddish brown. $\mathfrak{a}$ = yellowish green. Cross sections show the hornblende angle. The hornblende-phenocrysts are not so numerous nor so large as the augite-crystals.

In the groundmass the slender lath-shaped, frayed crystals of a pleocroic reddish brown or a green hornblende are a conspicuous feature. These, which are abundant, together with biotite, augite and magnetite, are distributed through a colorless feldspathic matrix and constitute the dark-colored constituents of the groundmass. An alkali feldspar, a secondary muscovite, and minute specks of calcite constitute the colorless portion of the groundmass. The presence of calcium carbonate is attested

both by the brightly polarizing specks and by the effervescence of the powdered rock. Apatite is particularly abundant in fine crystals and may be included in any of the other constituents.

Olivine.—Olivine occurs characteristically in small crystals and rounded grains of the first generation. The high index of refraction, high double-refraction, parallel extinction, and dispersion of the still unaltered grains are all characteristic of olivine. It is, however, an inconspicuous and infrequent constituent of the rock, and is much altered to serpentine, hematite and magnetite.

In the order of their abundance the primary constituents should be named as follows: feldspar, nepheline, augite, hornblende and olivine. Both the feldspar and nepheline occur in greater abundance than any one of the ferromagnesian constituents and together constitute perhaps two-thirds of the rock mass. The structure is not so characteristically that of either a dyke or surface rock as to make it possible to determine the exact position occupied by the rock when cooling.

The character of the crystallization indicates the comparatively slow cooling of a "*hypabyssische*" rock. This crystallization may have taken place along the edge of a deep-seated magma, throughout an intrusive magma or in the central part of a surface flow.

A determination of the exact species of this rock from the study of a single bowlder must be more or less inaccurate and hence undesirable. Since a generic term only, can be affixed to the rock, the choice lies between the nepheline-syenite-porphyry and the theralite-porphyry groups. The highly alkaline character of the feldspars which constitute so large a proportion of the rockmass relates the rock perhaps more closely to the nepheline-syenite-porphyry group than to the theralite-porphyries. Like the nepheline-syenite-porphyries described by Brögger, it contains accessory olivine,[1] and comparatively

[1] W. C. Brögger, Die Mineralien der Syenit-pegmatit-gänge der südnorwegischen Augit- und Nephelinsyenit. Groth's Zeitsch. für Krys. und Nien., Vol. XVI., pp. 32, 39.

abundant augite and hornblende.[1] A further justification of placing in the syenite group a rock showing so large an amount of the ferro-magnesian constituents is found in the new group of rocks recently described by Weed and Pirsson from the Highwood Mountains[2] and Yogo Peak,[3] Montana, in the lamprophyres of Gallatin, Jefferson and Madison counties, Montana, described by Merrill,[4] and in the banakites of the Yellowstone National Park and vicinity described by Iddings.[5]

Here we have a series of rocks with orthoclastic groundmasses combined with variable proportions of the ferro-magnesian silicates (augite, hornblende, biotite and olivine) with a wide silica range, all related to the syenite group.

Age.—That the drift material in the neighborhood of Columbus has its source from the north shore of Lake Huron in Canada and from northern Michigan was sufficiently indicated by petrographic study. Distinct types from the bowlders were matched both in the hand specimen and under the microscope to specimens taken from ledges in Canada and Michigan. While such matching was not valuable with the monotonous granites, gneisses and quartzites which constitute the great bulk of the bowlder material, a sufficient number of pronounced types were harmonized to establish both the age and the general source of the bowlder material.

Representatives of the Archæan, Algonkian, Cambrian and Lower Silurian formations are found among the bowlders. All the igneous material is undoubtedly pre-Cambrian or Cambrian. The presence of this member of the nepheline-syenite-porphyry group cannot be explained except on the supposition that it was, like the material among which it was found, brought

[1] W. C. BRÖGGER, Die Eruptivgesteine des Kristianiagebietes. I. Die Gesteine der Grorudit-Tinguait-Serie. Kristiania, 1894.

[2] Highwood Mountains of Montana, Bull. Geol. Soc. Amer., Vol. VI., p. 414.

[3] Igneous Rocks of Yogo Peak, Amer. Jour. Sci., Vol. L., No. 300, Dec. 1895, pp. 467–479.

[4] GEORGE P. MERRILL, Notes on Some Eruptive Rocks from Gallatin, Jefferson and Madison counties, Montana. Proc. U. S. Nat. Museum., Vol. XVII., pp. 665.

[5] J. P. IDDINGS, Absarokite-Shoshonite-Banakite Series, THE JOURNAL OF GEOLOGY, Vol. III., No. 8, Nov.–Dec. 1895, pp. 935–939.

to Ohio from a northern source, and is, like all the igneous drift material, of Cambrian or, more probably, pre-Cambrian age. A nepheline-syenite has been described by Dr. Adams[1] from southern Canada. A type related to the nepheline-basanite, Dr. Adams says, is known in Canada, in the vicinity of Montreal, where it forms dikes connected with the intrusive stock of Mt. Royal. There is no reason why a similar rock should not occur west of Montreal, and it may yet be described. It is impossible to say at present whether this nepheline-bearing rock is in any way related to these formations or is related as a dyke to some yet undescribed nepheline-syenite area on the north shore of Lake Huron. In any case it is a pre-Tertiary dike or surface, volcanic, resembling the modern type and thus affording another instance of the essential similarity of ancient and modern rock types.

F. BASCOM.

BRYN MAWR COLLEGE.

[1] F. D. ADAMS, on the occurrence of a large area of nepheline-syenite in the township of Dungannon, Ontario, Am. Jour. Sci., 198, pp. 10–18.

PETALOCRINUS MIRABILIS (*N. SP.*) AND A NEW AMERICAN FAUNA.

THE fossils described in the present paper were collected in Jones county, Iowa, by the junior author, Mrs. A. D. Davidson; the paper has been prepared by the senior author, Mr. Stuart Weller. The type specimens of the new species are deposited in Walker Museum at the University of Chicago.

The fauna of the Niagara period in America has much in common with that of the Wenlock limestone in England. There are at least thirty[1] species common to the two faunas, and the relationship is such as to make it seem most probable that during that period a shore line along which the fauna lived reached continuously across the Atlantic Ocean of today, joining the east American to the British regions. The fauna of the Gotland limestone of Sweden also has numerous species common to the Wenlock limestone and the Niagara. *Goniophyllum pyramidale* and the species of *Crotalocrinus* occur most abundantly in the Swedish beds though they are also present in the Wenlock limestone. The particular facies of the Silurian fauna containing *Goniophyllum* has not been generally recognized heretofore as American, and no crinoid has ever before been recorded which is at all closely related to *Crotalocrinus*.

Under these circumstances the discovery of a Silurian fauna in America containing specimens of *Goniophyllum* which cannot be separated specifically from those of the Swedish beds, associated with a crinoid whose nearest ally is *Crotalocrinus* is of extreme interest. Although it has seemed necessary to refer the crinoid not only to a distinct genus but even to a distinct family, it does not detract from the interest in the relationship of the faunas. It is well known that of all organisms which are preserved as fossils, none are more delicately adjusted to their

[1] Phillips Manual of Geol., Part II., p. 122 (1885).

environment than are the crinoids. Because of this it is not surprising that during a change or migration which did not even bring about a modification of the specific characters of the coral *Goniophyllum*, the generic and even family characters of the crinoid became modified. The peculiar family of *Crotalocrinidæ* has heretofore stood out alone among all the crinoids, and now a new family is discovered in America which is just as peculiar and whose bonds of relationship are strongest with the European *Crotalocrinus*.

Only a few of the most remarkable species of the fauna are described in the present paper. Corals are exceedingly abundant in the fauna, in fact it seems probable that these Iowa beds are the remnants of an ancient coral reef where many species of these animals flourished. It is hoped in the near future to make an exhaustive study of the whole fauna and its relationships.

PETALOCRINIDÆ (*n. fam.*).

No special description of the family will be attempted, all the characters, family, generic and specific, will be recorded under the description of the species.

PETALOCRINUS MIRABILIS (*n. gen. et sp.*).

Plate VI., Figs. 2–5.

The entire crinoid resembles a flower with five petals fully expanded, the five leaf-like arms representing the petals. The diameters of the calyces of the two perfect specimens in the collection with all the arms intact, are respectively $\frac{3}{16}$ and $\frac{1}{4}$ inch, the total expanse of the arms being $\frac{7}{8}$ and $1\frac{1}{8}$ inches. Some of the detached arms indicate individuals whose total expanse of arms was nearly two inches.

Calyx monocyclic, depressed. Basal plates 5, rhomboidal. In four of them the two outer edges are a little shorter than the inner; on the anal side the two outer edges are about equal to the inner. First radials resembling those in *Platycrinus*, a little wider than long, extending nearly horizontally from the basal plates. Second radials very short, free, as in *Platycrinus*, bearing the arms. They appear as thin plates intercalated

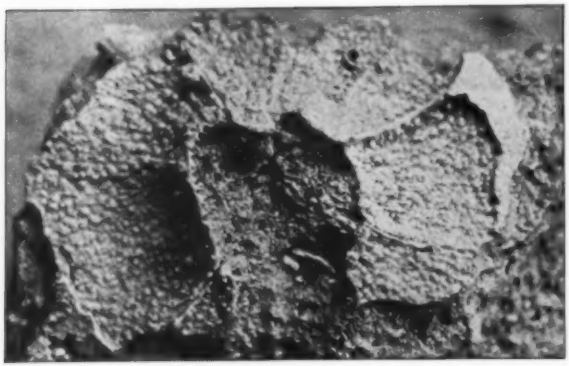


FIG. 1.

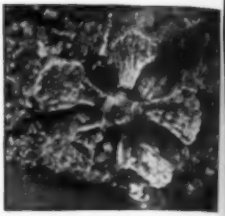


FIG. 2.

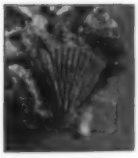


FIG. 5.

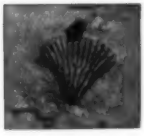


FIG. 4.

FIG. 3.

FIG. 6.

FIG. 7.

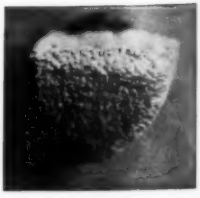


FIG. 8.

between the arm bases and the central portion of the outer edge of the first radials. No interradials observed on the dorsal aspect of the calyx. Ventral aspect unknown.

Arms triangular, leaf-like, rigid, gently curving dorsally. The plates composing them closely anchylosed, no sutures visible.[1] Dorsal side smooth, ventral side covered with longitudinal, rounded ambulacral grooves, separated by sharp ridges.

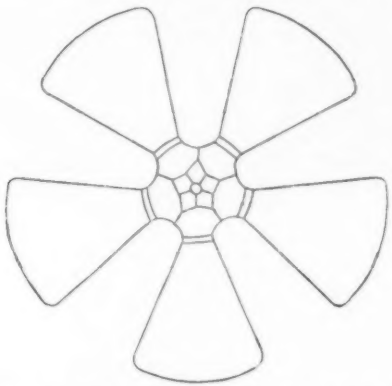


Fig. 1.—Outline view of the arrangement of the plates of the calyx and the relation of the arms to the calyx in *Petalocrinus mirabilis*.

Two ambulacral grooves start from the base of the arm, these bifurcate almost immediately, each of these four bifurcate and their branches bifurcate again, making sixteen ambulacral grooves at the distal edge of each arm.

Stem small, about one-sixth of the diameter of the calyx.

The structure of this crinoid does not conform to that of any described family, and it seems necessary to establish a new one for its reception. Were it not for the number of basals, the calyx alone would unhesitatingly be considered as belonging to *Platycrinus*. The most peculiar feature of the crinoid is its arms. In their broad leaf-like expanse they resemble somewhat closely those of the *Crotalocrinidæ*, but unlike the arms of the members of that

[1] The specimens are silicified, and in the process of silicification the sutures may have been obliterated. In another condition of preservation they might be observed.

family, they are perfectly rigid, standing out horizontally from the calyx and are entirely distinct from one another. They are also not nearly so greatly developed in *Petalocrinus* as in *Crotalocrinus*.

Fig. 2.—Idealized view of the ventral surface of an arm of *Petalocrinus mirabilis*.

The diameter of the stem is small, while in the *Crotalocrinidæ* it is almost as great as that of the entire calyx.

PETALOCRINUS (?) MAJOR (*n. sp.*).

Plate VI., Fig. 1.

A single imperfect specimen differs materially from the specimens of *P. mirabilis*. The calyx is entirely unknown, but from the arm structure it is placed provisionally in the genus *Petalocrinus*. The arms differ from *P. mirabilis* in being much larger and in being in lateral conjunction. The arrangement of the ambulacral grooves cannot be determined as the ventral surface is imbedded in the matrix. In the great expanse of the arms and their lateral conjunction this species approaches more nearly to the arm structure of *Crotalocrinus*, but differs from the species of that genus in their apparent rigidity.

GONIOPHYLLUM PYRAMIDALE [1] *Hisinger*.

Plate VI., Figs. 6–8.

829. *Turbinolia turbinata* var. *pyramidalis* Hisinger. Tableau des petrif. de Suede, Ed. 1, p. 22.

1831. *Turbinolia pyramidalis*, Hisinger. Tableau des petrif. de Suede, Ed. 2. p. 26.

1851. *Goniophyllum pyramidale* Milne Edwards & Haime, Polypiers fossiles, p. 404, Pl. 2, Figs. 4, 4*a*.

[1] For a complete bibliography of *G. pyramidale*, see Dr. Lindström's paper on the operculate corals.

1882. *Goniophyllum pyramidale* Lindström, Palæozoiska Formationernas Operkelbärande Koraller, p. 43, Plates 1, 5, 6, 7, 8, 9.
1890. *Goniophyllum pyramidale.* Am. Geologist, Vol. VI., p. 326.

The presence of *G. pyramidale* in the Silurian rocks of America has not been generally recognized, the short note in the American Geologist, which simply records the presence of the fossil in Iowa, being the only reference known to the writer. Dr. Lindström states in a communication to the writer that he has a single specimen of the species from Tennessee, which does not differ from the Swedish ones.

Dr. Gustaf Lindström has made an exhaustive study of the operculate corals, and he recognizes three forms of this species from the Swedish Silurian beds, viz., "*Forma primigena*," "*Mutatio prima*," and "*Mutatio secunda*." The Iowan specimens agree well with figures and descriptions and also with authentic Swedish specimens[1] of "*Mutatio secunda*" of Dr. Lindström. The species may be easily recognized by reason of its peculiar quadrangular form as shown in the figures. When perfectly preserved the calyx is covered by four triangular valves which form a pyramidal operculum. A single one of the Iowan specimens shows one of the operculum valves in position. The specimens vary among themselves in the amount of curvature and in the depth of calyx.

PENTAMERUS OBLONGUS *Sowerby, var.* CORRUGATUS, *n. var.*

Plate VII., Figs. 1–4.

This singular variety of *Pentamerus* is characterized by the criss-cross corrugation of the valves as is shown in the figures, and is apparently peculiar to this fauna. It is possible that it may become necessary to consider it as a distinct species, but as it does not differ from other variations of *P. oblongus* except in the criss-cross corrugation of the valves, and as this character is oftentimes faint or almost obsolete, it is thought best to accord to it but the taxonomic rank of a variety.

[1] The writer is indebted to Dr. Lindström for authentic specimens of *G. pyramidale* from Gotland.

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

STRICKLANDINIA CASTELLANA *White.*

1876. *Stricklandinia castellana* (*N. S.*) White. Proc. Acad. Nat. Sci. Phil. p. 30.

1894. *Stricklandinia castellana* Hall & Clarke, Rep. N. Y. State Geol. for 1893, Vol. II., Pl. 49, Figs. 1–3, 5. (Handbook of Brachiopoda, Part II.)

As this species is found in association with the preceding it is thought advisable to make note of it here, and as the original description is somewhat inaccessible it is copied in full:

Shell moderately large, sublenticular, broadly subovate or subcircular in marginal outline; valves almost equally convex.

Dorsal valve usually showing a slightly elevated, indistinctly defined mesial fold, which is quite narrow upon the posterior portion of the valve, but widens towards the front, of adult shells; umbo broadly convex; beak not prominent.

Ventral valve usually having a slight flattening of the antero-median portion, corresponding with the indistinct fold of the other valve; umbo broadly convex; beak not prominent, projecting backward little if any beyond the beak of the other valve; area distinct, narrow, its length less than half the greatest width of the shell.

Surface of both valves marked by numerous, rather coarse, radiating, more or less recurving, angular or sharply rounded plications of unequal size and separated by spaces of unequal width.

Length and breadth of the largest example discovered, each forty-two millimeters; thickness, both valves together, twenty-one millimeters.

EXPLANATION OF PLATES.[1]

Plate VI.

Fig. 1. *Petalocrinus (?) major.*

Figs. 2–5. *Petalocrinus mirabilis.*

Figs. 2, 3. Two specimens showing all the arms in position.

Fig. 4. An impression in the chert of the ventral surface of a detached arm.

Fig. 5. Ventral surface of a detached arm.

Figs. 6–8. *Goniophyllum pyramidale.*

Plate VII.

Figs. 1–4. *Pentamerus oblongus var. corrugatus.*

STUART WELLER.
A. D. DAVIDSON.

LABORATORY OF PALÆONTOLOGIC GEOLOGY,
UNIVERSITY OF CHICAGO.

[1] All the figures are natural size.

REMARKS ON *PETALODUS ALLEGHANIENSIS* LEIDY.

In an article entitled "Description of a New Species of Petalodus," etc. (this JOURNAL, Vol. III., No. 5), Dr. O. P. Hay describes an interesting specimen of a selachian tooth from the Carboniferous limestone of Illinois, for which he proposes the name *Petalodus securiger*. A number of characters are enumerated, in which the supposed new species is believed to differ from *P. alleghaniensis* and *P. destructor*, these two being regarded by the author as distinct. The article concludes with the suggestion that in case the identity of *P. alleghaniensis*, *destructor* and *securiger* ultimately be established, the name *P. ohioensis*, proposed by Professor J. M. Safford in 1853, should be reinstated on the ground of priority.

In the opinion of the present writer, all the forms described under the above names are identical, and as the validity of the well established title proposed by Leidy is brought into question, a few considerations may not be out of place in favor of its retention. These considerations would have been submitted much earlier, but for the fact that the writer has been awaiting an opportunity for comparing the Illinois specimen with the fine series of Petalodont teeth in the collection of the Museum of Comparative Zoölogy at Cambridge; he regrets, however, that a reported accident to the specimen has rendered it inaccessible to him.

As Dr. Hay does not state his reasons for preferring to regard *P. alleghaniensis* and *P. destructor* as distinct species, it may be as well to accept the opinion of Leidy, Newberry, St. John and others as authoritative, who hold that the two names are synonymous. In point of fact, less differences are to be noticed between specimens attributed to the above-named species than are exhibited by the teeth of the one species *P. acuminatus*

from limited localities in Yorkshire and Armagh. Attention has been called repeatedly to the great differences existing among detached teeth belonging to one and the same species, due to conditions of wear, age, geographical distribution, and other causes; and particularly to the wide range of variations displayed by teeth of the same individual, depending upon the position occupied in the mouth. In the case of *Petalodus*, we can infer what this second class of variations were, from analogy with the closely related genus *Janassa*. All of the minor differences in form and size which our author observes between *P. securiger* and *P. alleghaniensis* may be reasonably referred to this category.

The marked variation in the size of *P. alleghaniensis* correlating with geographical distribution has already been commented on by Newberry (Pal. Ohio, Vol. II., p. 53), the Ohio specimens being only about one-half as large as the western ones. Had our author compared his specimen with the figures and description of Leidy's type (Jour. Acad. Nat. Sci. Philad. [2], Vol. III., p. 162), instead of with the one figured in the Extinct Vertebrate Fauna, he would have found that the agreement is closer than he supposes; among other features, the number of basal enamel folds is precisely the same in both forms.

Finally, the rounding of the lateral angles (only one is preserved on Dr. Hay's specimen), can hardly be considered as of specific importance, since it, too, is a variable function; nor does the prominence of the enamel bands on the posterior surface appear to have any particular significance. The conclusion reached by the present writer is that at the most *P. securiger* is only a variety of *P. alleghaniensis*.

As to the availability of the terms *P. extinctus* and *P. ohioensis*, both are clearly untenable. Leidy's provisional designation of "*Sicarius extinctus*," proposed in 1856, was merely tentative, and unaccompanied by either figures or description of any kind. When, a few months later, the species was adequately described, this name was withdrawn, as was entirely proper, and that of *Petalodus alleghaniensis* substituted instead. In all probability

the specimen for which Safford proposed the name "*Getalodus Ohioensis*" was a true *P. alleghaniensis;* but this cannot be settled from the description, which is wholly insufficient, and the rough sketches of the tooth are not only unrecognizable, but, as Dr. Hay himself intimates, probably erroneous. Such being the case, it is in accordance with the ordinary rules of nomenclature that Professor Safford's term should lapse.

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ON THE NATURE OF IGNEOUS INTRUSIONS.

In an article in the preceding number of this JOURNAL, certain igneous intrusions in the vicinity of the Black Hills of Dakota, termed plutonic plugs, were described, and the similarity pointed out between the domes of sedimentary beds raised above them and the far greater dome from which the Black Hills have been sculptured. Other mountains of the Black Hills type in Wyoming and Colorado were also mentioned. In the present article I wish to direct attention to the fact that the dome-shaped uplifts referred to, form part of a genetically related series of disturbances caused by subterranean intrusions of igneous rock. Various stages in this series are shown by intruded sheets, laccolites plutonic plugs, and great dome-shaped uplifts of which the Black Hills furnish the type.

Intruded sheets.—As is well known, igneous rocks frequently occur in widely spread sheets, included between but litttle disturbed sedimentary strata. Although the enclosing sedimentary layers are frequently without conspicuous signs of having been disturbed, metamorphism of the sedimentary beds resting on the igneous rock at the surface of contact, furnishes proof that the latter was intruded in a molten condition between planes of bedding, after the sedimentary layers were consolidated. An example of an intruded sheet is furnished by the Palisade trap of New Jersey and New York. Including what is reasonably supposed to be a portion of this sheet, but which is separated from the main exposure by a covering of Cretaceous clays, its length measured along the curve formed by its outcrop is 90 miles. A straight line joining the most northern and most southern exposures is 70 miles in length. The sheet varies in thickness from about 300 feet at Jersey City, to at least 850 feet at

the High Torne, in Rockland county, New York.[1] The breadth of the surface now exposed by erosion, is from one to two miles. The central part of the sheet dips westward, in conformity with the enclosing strata, at an average angle of about 15°, but the dip increases toward the northern extension of the sheet, where irregularities occur. As shown by Darton, the dike that supplied the sheet, is exposed at a few localities on the western margin of the part now uncovered. The sheet does not, therefore, extend indefinitely beneath the sedimentary beds to the westward, as was at one time supposed. The Palisade sheet is remarkable for its extent and thickness, but except in these features, does not illustrate the facts to which I wish to direct attention, so well as many smaller examples of the same nature. In other portions of the Newark system, especially in the Connecticut valley, much thinner intrusive sheets occur, and many similar examples in other regions are familiar to most geologists. One of the best illustrations of the manner in which molten rock has been forced in between the strata of horizontally-bedded sedimentary rocks, which I have observed, may be seen in the precipitous walls of the canyon excavated by Purgatory River in Cretaceous terranes, in southeastern Colorado. The beds cut through in forming this canyon, include a sheet of basaltic rock four or five feet thick, which is exposed for three or four miles on each side of the gorge; so perfectly does it conform with the strata above and below, that even a careful observer seeing its outcropping edge for the first time from the bottom of the canyon, would not mistrust its intrusive origin.

In the case of the intrusive sheet exposed in Purgatory canyon, as already stated, the enclosing strata are horizontal. The same is true of similar sheets in many other regions. It is supposed with good reason that the intrusive sheets of the Newark system were forced in before the associated beds were tilted and faulted. The fact that intruded sheets are of frequent occurrence in regions where stratified rocks are yet horizontal is suggestive.

[1] N. H. DARTON, "The relation of the traps of the Newark system in the New Jersey region," U. S. Geological Survey. Bulletin No. 67, p. 44.

During the intrusion of a sheet of molten rock between horizontal strata, it is evident that the beds above the plane of intrusion must be lifted. The force which lifts the superior layers must be the dynamical energy of the intruded molten rock, aided perhaps by the steam generated when the highly heated magma came in contact with water. If intruded sheets were confined to the side of folds or to regions deformed in other ways, it might be suggested that the force which deformed the rocks tended to separate the strata, thus lessening the work that the intruded rock had to perform in order to make room for itself, but as intrusive sheets seem to be most common if not confined to regions where the receiving terrace is horizontal or was yet undisturbed at the time the intrusion took place, no such assistance can be claimed. That the receiving terrane should be practically horizontal at the time extensive intrusive sheets are formed, seems an essential condition, since folded and tilted strata are apt to be broken and faulted, and would thus furnish passages for the escape of the molten rock forced in among them under great pressure, and dikes and not sheets would result. Also, horizontally stratified beds would offer less resistance to the advance of an intruded sheet among them, than similar beds when folded, since the force necessary to split open the even grain of the horizontal beds, would be less than the force required to separate the contorted grain of folded beds.

Another significant fact, as shown by observation, is that intruded sheets of wide extent at least, are composed of basaltic rocks, that is of the most easily fusible of igneous rocks. Rocks of which basalt may be taken as the type form highly fluid magmas when heated to 2000° or 2500° F., a temperature at which more siliceous rocks like rhyolite, are still solid or at most only viscous. Intruded sheets, therefore, seem to have been formed by the injection of highly fluid magmas under great pressure. Just as easily fusible basaltic lavas, when ejected from volcanoes, tend to spread widely over the surface, so highly fluid magmas, when forced between stratified beds, spread out in thin intruded sheets. As highly viscous magmas, when extruded at

the surface, flow sluggishly and frequently come to rest in thick masses even on steep slopes, it is to be inferred that if such magmas were intruded in a manner similar to that by which sheets of basalt are spread between sedimentary strata, they would expand much less widely. This difference in freedom of flow between magmas that are easily fusible and those that are refractory, appears to be one of the conditions which determines whether a body of highly heated rock intruded among horizontally stratified beds, shall spread widely and form a sheet, or be restricted in its lateral expansion and cause a more local uplift of the strata above it.

Another condition which would influence the behavior of an intruded magma, is the depth in the earth's crust at which the intrusion occurs. Since the rocks above the intruded magma have to be lifted, the higher in the series the intrusion occurs, the less the weight of the rocks above, and the greater the amount of energy available for lateral expansion. If variations in the specific gravity of strata are not considered, the conditions favoring the formation of intruded sheets, increase as the magma approaches the surface, until the tendency of the lifted strata to fracture determines a limit. We should expect, therefore, that intruded sheets would be most numerous in the upper portion of the earth's crust. The correctness of this inference can be tested to some extent by observation. The date at which many intrusive sheets were formed, however, and the amount of subsequent erosion that has taken place, are frequently difficult to determine and space will not permit of the introduction of evidence in this connection. The fact that the edges of intruded sheets are frequently exposed in canyon walls in regions of topographic youth, certainly favors the conclusion that widely extended intrusive sheets are comparatively superficial phenomena.

In order to bring the ideas which I wish to present to a focus, let us consider other phases of igneous intrusion.

Laccolites.—The difference between a widely extended intrusive sheet and a local cistern-like injection of molten rock, or a laccolite, so far as the shape of the intruded mass is concerned,

is mainly in the degree of lateral expansion. In what may be termed their genetic features, these two classes of intrusions are essentially similar. In each case molten rock rises from below into stratified beds, probably through fractures, and on reaching the upper limit of the fractures lateral expansion takes place and the strata above are lifted. The main conditions, as we have seen, which control the extent of the lateral expansion, besides the propelling force and the occurrence of fractures or other openings through which the molten rocks rise, are the fluidity of the magmas, and the depth in the earth's crust at which they reach the upper limit of the passage-way through which they came, and tend to spread horizontally. Under the same conditions respecting temperature and pressure, we should expect refractory magmas to form laccolites, while more easily fusible rock would be more apt to spread out in sheets.[1] We should expect laccolite, therefore, to be composed of less easily fusible rocks than are found in widely extended sheets. Again we may test inference by observation. It is usually conceded that the amount of silica in a rock determines its degree of fusibility. Acid rocks, as a rule, are more refractory than basic rocks. Dana has qualified this conclusion, however, by showing that it is the fusibility of the chief constituent minerals in a lava which determines its mobility. He says: "Trachyte and rhyolite are the least fusible of igneous rocks, because the constituent feldspar, orthoclase, is the least fusible of the feldspars; and basalt or dolerite is one of the most fusible, because the feldspar present, labradorite, is of easy fusibility, and it is combined in the rock with still more fusible augite and pyroxene."

In a recently published report on the laccolitic mountains of

[1] Intruded sheets do occur in connection with the laccolites, and are composed of off-shoots of the same material. Sometimes these sheets, as stated by Cross, extend four or five miles from the main intrusion. As shown in sections of Henry Mountains, given by Gilbert, the associated dikes and sheets are in the disturbed strata above and immediately about the main body of the laccolites. The opening of the deformed strata by the disturbance caused by the principal intrusion appears to have had much to do with the origin of the secondary phenomena. It does not seem to me that the comparatively small sheets originating in this manner furnish an exception to the generalization suggested above.

Utah, Colorado and Arizona, Cross[1] states that the rocks composing these intrusive bodies all belong to a well marked structural type and present but slight variations in mineralogical composition. Plagioclase is the predominant mineral of all the rocks—excepting the quartz-porphyry—and the uniform appearance of its stout white crystals gives character to the whole series. Which of the feldspars composing the group known as *plagioclase*, are most common in these rocks is not clearly stated, but in a table of nineteen analyses, the percentage of silica ranges from 56.62 to 73.50, and of alumina 14.87 to 18.00. The rocks are therefore highly siliceous, and, I think I am justified in concluding, highly refractory, in comparison with the basaltic rocks of which widely extended intrusive sheets are composed.

It appears, therefore, that the nature of an intruded magma, whether highly fluid or viscous, has much to do with the form in which it solidifies. The degree of fusion depends, of course, on the amount of heat. Even the most refractory rocks, when sufficiently heated, will become highly fluid, under normal surface pressure. Since the interior heat of the earth increases with depth, refractory rocks would remain unmelted, or perhaps be partially fused and viscous, at a depth where the most easily fused igneous rocks would be highly fluid. This would lead us to expect also that laccolites would be formed deep in the earth's crust. This inference can be checked by observation. Evidently, if laccolites are now exposed at the earth's surface, the amount of erosion that has taken place in the disturbed beds above them will show how deeply they were originally buried. In the case of the Henry Mountains, Gilbert shows that the domes of stratified beds removed were possibly 7700 feet thick.

The relative specific gravity of intruded magmas may also be expected to influence their behavior, and especially the height to which they would rise under a given pressure, but this seems to be a minor feature of the problem. The force with which magmas are injected is, of course, the main cause which deter-

[1] U. S. Geological Survey. Fourteenth Annual Report, pp. 224, 228.

mines this behavior, but the principle which interests us most at present, is that different magmas under the operation of similar pressure tending to intrude them, would behave differently. The conditions that modify and limit the formation of laccolites have been fully discussed by Gilbert,[1] and need not be reviewed at this time.

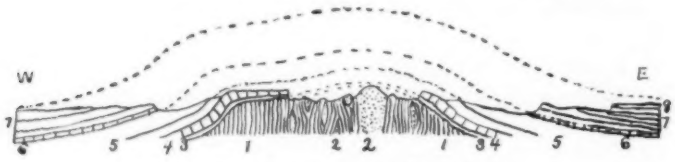
Plutonic plugs.—In a previous article in this JOURNAL, already referred to, I have directed attention to the plug-like intrusions that occur in the Black Hills region. These intruded masses have been classed as laccolites by Crosby, and possibly the variation they present from that type is not sufficient to necessitate a separate consideration. They occur in a region where the stratified rock into which they were forced are essentially horizontal, and where dikes and other evidences of fracture are absent, and where deep erosion has occurred. They are formed of refractory acid rock. The principal mineral constituent, according to Casswell, is always sanadine.

The Black Hills of Dakota.—As pointed out in the essay referred to above, and as previously stated by Newton in his report on the Black Hills, the domes of sedimentary strata upheaved by the intrusion of plugs of igneous rock in the case of the Sun Dance hills, Inyan Kara, etc., are structurally identical with the vast Black Hills dome. In each case previously horizontal strata were raised by a force acting from below vertically upward, so as to form a dome from the summit of which the layers dip away in all directions. The dome known as Little Sun Dance hill is unbroken by fractures and the summit of the plug of igneous rock inferred to exist beneath it, is not exposed. The absence of dikes in connection with the associated uplifts indicates that they, also, were not fractured as they rose, so as to allow the fluid rock beneath to escape. The absence of dikes indicates that the intrusion of the plugs took place at great depths, and that the upraised strata were under heavy pressure. The strata, after being upraised, were certainly of greater superficial extent than previously, when horizontal, and a stretching

[1] Report on the geology of the Henry Mountains.

and thinning of the beds over the summit of the dome is to be inferred, but thus far has not been observed.

The Little Sun Dance dome is about a mile in diameter. The Inyan Kara dome measures about two miles in diameter. The similar dome from which Warren Peak has been sculptured, was two or three by eight miles in diameter. The Black Hills dome, as shown by Newton and Gilbert, is less regular in ground



IDEAL CROSS-SECTION OF THE BLACK HILLS.

Vertical scale 5–6 times horizontal. Dotted lines indicate portion of uplift removed by erosion.

1. Archæan slates and schists.
2. Granite.
3. Potsdam unconformably on 1 and 2.
4. Carboniferous.
5. Red beds.
6. Jura.
7. Cretaceous.
8. White River Tertiary unconformably on 7.

plan than those just mentioned, and measures 70 by 160 miles in diameter.

The plugs of igneous rock which lead to the elevation of the Inyan Kara and several associated domes, have been exposed by erosion, and rise boldly in the center of the encircling rings formed by the truncation of the domes that formerly arched over and concealed them. In the center of the concentric outcrops of stratified rocks forming the outskirts of the Black Hills, there is a mass of schists into which a core of granitic rock has been intruded. The succession of stratified rocks forming the dome, and their relation to the schists and granites within, is shown in the following section copied from Newton and Gilbert. It is to be remembered that any cross section through the Black Hills uplift would show the same structure, although the details would be varied.

The schists shown in the central part of the section, belong to the series of stratified rock resting on them, so far as the origin

and general structure of the uplift are concerned, and shared in the disturbance that elevated them. Whether the core of intruded granite answers to the plutonic plugs forming the cores of the smaller domes or has itself been elevated by an intrusion of molten rocks beneath, will be considered in advance.

Under this view of the origin of the Black Hills dome, the supposed intrusion of molten rock took place deep below the surface, and on account of the vast weight to be lifted, and probably also by reason of its viscosity, did not expand into a broad sheet, but as in the case of true laccolites, and plutonic plugs, produced a local elevation. The deeper the horizon at which the intruded rock expanded, the broader would be the dome formed above it. The outline of the dome raised on the surface would depend on the form of the cistern of molten rock beneath, and perhaps on the dip of stratified beds before the intrusion occurred. If the subterranean cistern was supplied through an extended fissure, an elongated dome or a ridge-like elevation at the surface would result. The domes produced by the injection of plutonic plugs, as already stated, are nearly circular, but the major axis of the Black Hills dome is double the length of the minor axis. The form that the elongated Black Hills dome would present, had there been no erosion, is shown on a contour map by Newton and Gilbert.[1]

The influence of dip on the form of an uplift produced in the manner above considered, is probably not important, as it is doubtful if such deformation occurs in rocks that are not essentially horizontal.

Mountains of the same type as the Black Hills but in which the difference between the horizontal axes is greater, occur in the same general region.

The mountains of Wyoming and Colorado.—The Big Horn Mountains, Wyoming, are of the same type as the Black Hills uplift, but the dome from which they were sculptured was more elongated than is the case of the Black Hills dome. The trend of the range is approximately northwest and southeast, but is

[1] Report on the Geology of the Black Hills, plate opposite page 208.

concave on the west, the longer diameter of the now truncated dome is 160 miles and its shorter diameter about 50 miles. At the south this uplift merges with another of similar character which trends more nearly east and west and has been deeply eroded. Its central mass of weathered granite forms the Wind River Mountains. Mountains having the same structure, extend southward into Colorado, and form several ranges designated by Powell as the Park Mountains. Each of these dome-like uplifts of Wyoming and Colorado has been deeply eroded, and broad central cores of granite exposed and sculptured into bold topographic forms. Sections through the mountains of Colorado from east to west, published in the "Atlas of Colorado," by Hayden, and the atlas accompanying the reports of the Fortieth Parallel Survey, show great central masses of what is termed metamorphic granite. On the flanks of these central masses the sedimentary strata underlying the adjacent plains, are sharply upturned. In many instances the central granitic cores are from 20 to 30 and even 50 to 60 or more miles across.

These dome-like arches are clearly not anticlinical folds; although, that such was their origin has frequently been stated. Nothing in the Appalachian or other similar ranges, formed by the crumpling of stratified beds by lateral compression, corresponds with them. Experiments with plastic material in illustration of the formation of anticlines and synclines, do not suggest that such broad, simple arches surrounded by horizontal strata can be produced in the same manner. These great upward bulges are similar to the Black Hills dome, the only conspicuous difference being that they are much elongated. If we arrange in a series, cross sections of the Black Hills, Big Horn, and Wind River Mountains and of several of the ranges included in the Park Mountains, it will be seen that a single type of uplift is shown in all cases. The same fact will appear also if restorations of the various domes as they would appear had there been no erosion, are placed side by side. That several of the more prominent ranges of Wyoming and eastern Colorado are of one type, was recognized by Hayden, who considers them, however,

as have others, of the nature of anticlinals produced by lateral compression. He says:[1]

> In general terms, while the details are extremely complicated, we may express the structure of a belt of country known as the Sawatch range (in east-central Colorado), eighty miles in length from north to south, and at least forty from east to west as a single wedge of granite, thrust upward, and the sedimentary rocks inclined from either side. The illustration of which the Sawatch range is the central mass is probably on a grander scale than any other in the West, but there are abundant examples of smaller size. The Black Hills of Dakota, the Laramie range, Big Horn, Wind River and many others are of the same type.

The cores exposed in the Black Hills, Big Horn and other mountains referred to above, are of granite. Whether these granitic centers answer to the plutonic plugs in the smaller domes to the northward of the Black Hills, or belong structurally to the sedimentary beds upturned on their flanks, and have themselves been elevated by intrusions beneath, is not clear. I am inclined to the hypothesis, however, that the granite was the floor on which the sedimentary beds were deposited and that it has itself been elevated with them.

The magnitude of the elongated domes from which the present mountains of Colorado and Wyoming have been sculptured, might perhaps be urged as an objection to the view of their origin here expressed. As it will tend to make us more cautious if the size of the problem we have attacked is fully realized, let us endeavor to form a mental conception of the region referred to as it would appear under this hypothesis, if unaffected by erosion.

On the summit of Mt. Lincoln, Colorado, 14,297 feet above the sea, there are, according to Hayden, clastic beds belonging to the same series as the strata upturned on the flanks of the mountains of which Mt. Lincoln is one of the dominant peaks. No one who is familiar with the geology of Colorado will dispute, I fancy, that this and other similar evidence, may be taken as proof that the granite now forming the central

[1] U. S. Geological and Geographical Survey of the Territories, annual report for the year 1873, p. 49.

peaks of the several ranges termed the Park Mountains, was once covered by an extension of the formations now found beneath the intervening valley, and upturned on the flanks of the uplifts.

As the central cores of granite now rise between seven and eight thousand feet above the adjacent border of the Great Plains, the refilling of the gorges and valleys excavated in their sides, so as to restore what would have been the surface contour of the granite had there been no erosion, would produce an elongated dome rising at least seven or eight thousand feet above the adjacent plain on the east. If we add to the surface of this dome the thickness of sedimentary beds now upturned in its eroded flanks, its height will be increased by seven or eight thousand feet; this being the approximate average thickness of the upturned border of the strata that extend horizontally beneath the Great Plains.

The most severe test of the hypothesis before us, in respect to the magnitude of the results reached, is furnished by what is known as the Front Range of the Rockies in Colorado and Wyoming. This range is probably not the result of the wearing away of a single dome, but as the central granite core now exposed is continuous from Central Wyoming to southeastern Colorado, a distance measured along the curve of the outcrop, of about 400 miles, we will consider it for the present, as an individual uplift. The average breadth of the granite is between twenty and twenty-five miles. The great elongated dome from which the Front Range of the Rockies has been sculptured, would therefore if uneroded, have a length in excess of 400 miles, a breadth of probably 40 or 50 miles and a height above the level of Denver of 15,000 to 16,000 feet.

This result reached by pressing our hypothesis to its logical conclusion—and assuming in order to make the test as severe as possible, that the Front Range is a single uplift—is startling, it is true, but no more so than the measures of the amount of erosion that have been obtained in an adjacent region. In the Uinta Mountains, Powell finds that the mean thickness of rock

which has been eroded away from a large area, is 18,500 feet, and in the axial region of the mountains, is 25,000 feet.

From the broad oval summit of the great dome we have restored in fancy by prolonging the remnants of the base of the arch over the central granitic peaks, we can see lesser domes which form a series and lead step by step down to the Little Sun Dance dome, a mile in diameter, the inner layers of which remain to this day unbroken.

As the type of mountain briefly described above is distinct from other types usually recognized, it will be convenient to designate it by an appropriate name. To meet this want, I venture to suggest that uplifts which owe their origin to the intrusion of a molten magma into the rocks beneath them, be termed *subtuberant mountains*. They may be fancied to originate from the growth of a tuber within the earth's crust.

General conclusions.—From the facts to which attention has been directed, it seems to me that a sequence is traceable between: (1) Intruded sheets of the Palisade type, formed by highly fluid magmas spreading widely between horizontally stratified beds, and lifting a broad cover without producing conspicuous topographic changes or marked disturbances in the upraised beds. (2) More local intrusions of less fluid magmas forced into horizontally stratified beds, which raised the strata above into domes, as is the case of the Henry Mountains, the Sun Dance hills, etc., and (3) deeply seated intrusions probably of highly viscous magmas, which raised vast domes of sedimentary rock and the floor of metamorphic rock on which they repose, as in the case of the Black Hills, Big Horn, and Park Mountains.

To the question, whence came the force that was enabled to intrude sheets of molten material scores and even hundreds of square miles in area, between sedimentary layers, and lift beds of rock of the same extent and, in at least some instances, many hundreds of feet thick; or elevate domes from 50 to 200 miles or more in diameter, to a height of several thousand feet, only general answers can be given.

On the theory that the interior of the earth is in a highly

heated and plastic condition and enclosed in a more rigid shell which contracts as it cools, a force is brought to bear on the plastic interior which tends to squeeze it out whenever an opportunity is afforded. The idea is not that the crust of the earth is a cold and solid shell enclosing a molten interior, the surface of contact between the two being sharply defined; but rather that the highly heated and plastic interior passes by insensible gradations into a cooler and more solid exterior, the outer surface of which is cold and rigid. The crust is still losing heat and consequently contracting and thus brings a pressure to bear not only on the interior mass but on the material forming the crust itself. On account of irregularities and unequal cooling, regions well within what may be termed the crust, may still be in a molten condition. Such bodies of plastic material may differ from the rocks enclosing them, as well as vary in composition among themselves, by reason of having reached different stages in the process of change from a molten to a solid condition. Here again we are departing from observed conditions, and have only the imagination to guide us, as there are no tests available by which the truth of our conceptions can be verified.

Under the conditions assumed, when a fissure is formed in the earth's crust, the deeply seated fluid or plastic material within, is forced out and becomes more and more fluid as it rises and pressure is relieved, unless this tendency is more than counteracted by the decrease of fluidity due to loss of heat. When such fissures open a way to the surface volcanic phenomena ensue. If the fissures do not reach the surface but terminate in horizontally stratified rocks, the molten material which rises in them may spread more or less horizontally between the strata and form sheets, or exert its force locally and cause a dome to rise, according to its viscosity, the depth below the surface, etc.

Nothing less than the force produced by the contraction of a cooling globe seems adequate to account for the results to which attention has been directed. The slowness with which the earth has lost heat and the consequent slowness with which contraction has acted on the still plastic interior or still plastic reservoirs

in the crust itself, is in harmony with the gradual bending of strata thousands of feet in thickness, as seen in the Black Hills, Big Horn Mountains, etc., without producing fractures through which the igneous material could escape.

Certain broad physical features of the earth seem in harmony, also, with the views here advanced. It has long been recognized that volcanoes are arranged about the borders of continents, and on the ocean's floor. So far as the association of oceanic waters is concerned with the origin of volcanoes, this arrangement is now considered accidental. But as shown by Dana, volcanoes mark lines of weakness in the earth's crust. These lines of weakness may reasonably be supposed to be the direction taken by the fractures during an early stage in the cooling of the globe and to have continued to be the lines of weakness along which movements have taken place from time to time, down to our own day. In the central portions of continental areas, active and recently extinct volcanoes are much less numerous than near continental margins. In the case of those that do occur far inland, as in the Great Basin region, there is plain evidence that the rocks of the earth's crust have been broken, and the region is as much a line of weakness as if it chanced to be adjacent to the sea.

While active and recently extinct volcanoes are notably absent from the central portions of continental areas, it is equally true so far as can be judged from available data, that subtuberant mountains are confined to such central regions. This follows also from the conclusions that broad areas of horizontal and unbroken stratified rocks are favorable for the formation of extensive intrusions.

The central portions of continental areas although not lines of weakness in the sense used by Dana, are regions of denudation and, as has been recognized by several American geologists, may be considered as relatively light areas, in comparison with continental borders, where maximum sedimentation takes place. It is in regions where the earth's crust is relatively light, when fractures are absent, and where the strata are essentially horizon-

tal, that pressure brought to bear on the plastic interior—either by reason of the cooling and contraction of the earth's crust, or by the shifting of material on the surface, in the constantly active processes of denudation, transportation and sedimentation—would most reasonably be expected to cause the rocks to bulge upward into domes.

If the above considerations are well founded we should expect to find subtuberant uplifts in the central portions of continental areas, but not about their borders. Here, again, it would be well to check inference by observation, but so far as I am aware, mountains of the type referred to, have not been recognized outside of the United States. Although unable to verify our conclusion, at present, we can leave it as a prediction, the truth or fallacy of which will appear as exploration is continued.

Analogies between subterranean and surface igneous phenomena.—Certain analogies between the phenomena associated with subterranean intrusions and with surface extrusions or volcanoes, are of interest.

Quiet eruptions of highly liquid basaltic lava, like those characteristic of the Hawaiian volcanoes, are represented below the surface by widely extended intrusive sheets of similar material. The thick and sluggish volcanic flows of rhyolite of the character to be seen on the side of the Mono craters, California, are suggested by the cistern-like intrusions of refractory porphyrite, forming laccolites, and still more strongly by plutonic plugs in which no lateral expansion has been recognized. Fissure eruptions, like those that furnished the Columbia lava of Idaho, Washington and Oregon, or the Deccan traps of India, so far as the energy manifest, and the extent of topographic changes produced, are concerned, find more than a counterpart in subtuberant mountains.

Extremely violent volcanic explosions occur when large bodies of water come in contact with molten lava. A molten magma rising from a deeply seated source in the earth's crust, as a rule, invades strata that are more and more highly water-charged, the nearer it approaches the surface. A secondary

result of such an intrusion is the generation of steam. In the case of the intrusion of a plutonic plug for example, steam may be generated and assist in raising the dome that is formed in the stratified beds above. When a plutonic plug on approaching the surface comes in contact with subterranean water, sufficient steam may be generated to blow away the dome above. Surface explosions sometimes remove large portions of volcanic mountains, as in the case of Krakatoa, Somma, Santorin, Barren Island, Coseguina, Crater Lake, etc.; plutonic explosions may reasonably be supposed to remove domes of stratified rock (consisting either wholly of sedimentary beds, or made up in part of lava sheets), and form crater-like depressions termed crater-rings, calderas, etc., as in the case of Coon Butte, Arizona; Lonas Lake, India; and still greater cavities, like those occupied by Lakes Bolsena and Bracciano, Italy, the former of which is circular and six and one-half miles in diameter, and the latter less regular, with a north and south diameter of ten and one-quarter miles, and a breadth of nine miles.

The breaking of the steam bubbles that rise through the boiling lava in the crater of Vesuvius cause the summit of the mountain to tremble with miniature earthquake shocks. When the throat of the volcano becomes clogged, steam generated within breaks through the obstruction or rends the mountain with such violence that the region for miles around is severely shaken. Subterranean intrusions of molten rock on coming in contact with water, may reasonably be supposed to cause similar steam explosions of which the only surface manifestations would be earthquake shocks.

Since my essay on the plutonic plugs of the Black Hills region was published, my attention has been directed to the fact that the rocks, of which some of the plugs are composed, have been recently studied in the light of more modern petrographical methods than were employed by Caswell. L. V. Pirsson, states, in the Am. Jour. Sci., Vol. XLVII., 1894, pp. 341–346, that the rock forming the cores of Mato Teepee and the Little

Missouri Buttes, is phonolite, instead of sanadine-trachyte, the conspicuous feldspar being "soda-orthoclase or anorthoclase." A chemical analysis of the rock gave SiO_2 61.08, and Al_2O_3 18.71. "A vertical dike about fifty feet wide, cutting through the schist and Palæozoic series in the mountains south of Deadwood," observed by C. E. Beecher, is also mentioned.

Observations by W. M. Dawson, W. H. Weed and L. V. Pirsson, seem to show that domes with cores of plutonic rock and surrounded by horizontally stratified beds, similar to the domes with plutonic plugs in the neighborhood of the Black Hills, form the Sweet Grass Hills and Zogo Peak, Montana.[1]

Errata.—The titles of Figs. A and B, Plate II., Vol. IV. of this JOURNAL, should be transposed. The title for Fig. A should read, "Little Missouri Buttes from the East."

ISRAEL C. RUSSELL.

[1] "Report upon Country in the Vicinity of Bow and Belly Rivers, Northwest Territory, in Geol. and Nat. Hist. Sur. and Mus. of Canada, Report of Progress, 1882–3–4, c. pp. 16, 45.

W. H. WEED and L. V. PIRSSON, "On the Igneous Rocks of the Sweet Grass Hills, Montana," in Am. Jour. Sci., Vol. L., 1895, pp. 309–313.

L. V. PIRSSON, "On Some Phonolitic Rocks from Montana," in Am. Jour. Sci., Vol. L., 1895, pp. 394–399.

W. H. WEED and L. V. PIRSSON, "Igneous Rocks of Zogo Peak, Montana," in Am. Jour. Sci., Vol. L., 1895, pp. 467–479.

STUDIES FOR STUDENTS.

DEFORMATION OF ROCKS.[1]

I. GENERAL.

ROCK units under thrust act very differently, depending upon their thickness, strength, and other characters, upon the character and thickness of the rock units above and below, and upon the closeness of the folding.

It is believed that the outer part of the earth may be divided into three zones: (1) An upper zone of fracture; (2) a middle zone of combined fracture and plasticity; (3) a lower zone of plasticity.

(1) *Rocks under less weight than their ultimate strength when rapidly deformed are in the zone of fracture.* That is, when rocks under such conditions are deformed they break, and crevices small or great separate the broken parts. The fractured rocks may be jointed, faulted, or brecciated in a simple or complex manner. The fractures may be far apart and of great size and extent, or near together and of small size and extent. Innumerable parallel fractures may occur in the same direction when, as shown in a subsequent paper, the rocks develop a parting or fissility. In extreme cases of fracture the rocks become autoclastic or are broken into innumerable fragments by the forces of deformation. These

[1] Published by permission of the Director of the United States Geological Survey. In the preparation of this series of papers I have been greatly assisted by PROFESSOR L. M. HOSKINS. In the Sixteenth Annual Report of the United States Geological Survey, where my entire paper will appear, PROFESSOR HOSKINS's work, from which extracts are below made, will also be published. To WILLIS's paper upon the Appalachians I am also greatly indebted. ("The Mechanics of Appalachian Structure," by BAILEY WILLIS, Thirteenth Ann. Rept. U. S. Geol. Surv., pp. 211–281.) I should also mention HEIM's great work, "Mechanismus der Gebirgsbildungen," from which I have absorbed many ideas.

fragments may be rounded, and such rocks resemble ordinary clastic rocks. In this case the rock becomes a pseudo-conglomerate, and there are all gradations between such a rock and one in which the cracks and crevices become subordinate, the deformation being chiefly that of flowage. For a soft shale, but a small thickness of superincumbent strata, possibly 500 meters or less, may prevent any considerable fractures and crevices from forming. For the strongest massive rocks, a great thickness of superincumbent strata, possibly nearly 10,000 meters, may be necessary to prevent cracks and crevices from forming.

Heim states that it is impossible for crevices and cracks to exist at so great a depth as 5000 meters.[1] From geological observations I have for some time been convinced that a greater depth than this is required to close crevices under some conditions. The depth at which a cavity of any definite size begins to close will depend upon its form, upon the strength of the rock, upon whether the rock is saturated with water, upon the increased plasticity of the rock due to the rise of temperature with increased depth, upon the amount of lateral thrust, and upon the length of time during which the rock is subjected to stress.

So large an opening as the St. Gothard tunnel, 6.4 meters high and 8 meters wide, exists with no observed tendency to close under an irregular dome of rock which for some distance is more than a mile thick and has a maximum thickness of 1830 meters. The thickness of the superincumbent rock diminishes from the maximum to nothing at the ends of the tunnel. However, it would appear from this case to be highly probable that in order to close cavities the maximum number must be multiplied by a factor of considerable magnitude.

It would seem that mathematicians and physicists, after experiments upon the plasticity of rocks of different kinds, ought to give an approximate solution of the problem as to the depth at which cavities in any kind of rock would begin to close. We need long continued experiments upon the plasticity of different rocks at various temperatures and pressures, and while the rocks

[1] Mechanismus der Gebirgsbildungen, by ALBERT HEIM, Band II., 1878, p. 110.

are saturated with superheated water. We also need a satisfactory theory of the flow of viscous liquids or plastic solids.

In the absence of these data a first approximate solution of the problem has been made by Professor L. M. Hoskins, of Stanford University, based upon the elastic limit and the ultimate strength of rocks. The most carefully conducted experiments agree with theory and seem to show that rock masses of the same form have the same crushing strength per unit of area whether in large or small masses. In experiments on cubes running from 1 to 12 inches in diameter,[1] in each set there are irregular variations per unit area on each side of the average, but these are probably explained by the unavoidable variations in the strength of the different pieces tested and the impossibility of obtaining exactly similar conditions.

Professor Hoskins, after a comprehensive discussion, reaches the following general conclusions upon the closing of cavities in rocks:

(I.) In any region if the three principal stresses of a rock mass are equal, a spherical cavity cannot exist permanently if the normal stress in the rock exceeds the pressure within the cavity by as much as two-thirds the elastic limit or the ultimate strength.

(II.) If two of the three principal stresses are equal, a cylindrical cavity of considerable length whose axis is parallel to the third direction cannot exist permanently if either of the equal principal stresses exceeds the interior pressure by as much as half the elastic limit or the ultimate strength, or if the third principal stress exceeds the interior pressure by as much as half the elastic limit or ultimate strength.

Although the discussion has been confined to these special cases, it seems safe to state the following general proposition as at least probably true:

(III.) No cavity can exist permanently in a rock throughout a considerable portion of which the normal stress in any direction exceeds the pressure within the cavity by as much as the elastic limit or ultimate strength of the rock.

Professor Hoskins further says that:

The intensity of stress upon a horizontal plane at any depth is equal to the weight of a column of rock of unit cross-section extending to the surface.

[1] Tests of metals and other materials for industrial purposes, made with the United States testing machine at Watertown Arsenal, Mass., by S. V. Benét, Chief of Ordnance. Rept. of Chief of Ordnance for year ending June 30, 1884, pp. 126, 166, 167 188–199, 212, Washington, 1886.

In applying these results to ascertain the depth at which cavities would close, the following additional assumptions are made: Some of the cavities are supposed to have a form best adapted to resist closing. In most cases, as shown by Professor Hoskins, this is probably spherical. The cavities are supposed to be very small as compared with their depth below the surface, so that the pressure due to gravity is practically the same for all parts of a cavity. The rocks are assumed as being among the strongest — that is, having a crushing strength of 1700 kilograms per square centimeter. This amount somewhat exceeds the average crushing strength of the ordinary crystalline rocks, such as granite and schist, but is surpassed by about one-fifth in some of the very strongest hornblende-granites and basic rocks. It is probable that the stronger, and perhaps the strongest, rocks should be chosen, for the minute cavities in the interstices are concerned, and these can only be closed by the crushing or flowing of the individual mineral particles. Upon the one hand it is natural to suppose that some of the minerals composing rocks are stronger than any rock. Upon the other hand the cavities may be largely closed by the flowage or fracture of the weaker minerals of a given rock. However this may be, for the purposes of the present discussion it is plain that sandstones are to be placed upon the same basis as quartzites, and possibly shales upon the same basis as slates and schists.

The specific gravity of the outer crust of the earth is assumed to be 2.7.[1] As openings in the earth are usually filled with water, in obtaining a maximum depth at which cavities can exist permanently, it is probably necessary to suppose that cavities are supported by the hydrostatic pressure of a column of water reaching to the surface, and therefore that 1 should be subtracted from the specific gravity of the rock in determining the depth at which the closing of cavities occurs. Under the slowly acting orogenic forces it is probable that the water must be

[1] This estimate of 2.7 was kindly furnished me by Mr. G. K. GILBERT as a close approximation to the specific gravity of the continental masses. It is the same as my own best guess of the specific gravity of the pre-Cambrian rocks.

considered as free to escape, and that the viscosity of water in minute crevices plays no part.

If it be supposed that the rocks above the cavities are solid to the surface, and therefore that they are not supported by the hydrostatic pressure of a column of water to the surface, the problem is reduced by Professor Hoskins' solution to finding the height of a column 1 square centimeter in area, with a specific gravity of 2.7, which weighs two-thirds of 1700 kilograms for Conclusion I., and weighs 1700 kilograms for Conclusion III. This gives for I. about 4200 meters; for III. about 6300 meters.

If the more probable supposition be made, that the rocks are porous, and therefore that the cavities are supported by the hydrostatic pressure of a column of water extending to the surface, it is necessary to subtract 1 from the specific gravity of the rocks, and the effective pressure is 1.7 grams per cubic centimeter. Applying Professor Hoskins' solution, the question is reduced to finding the height of a column 1 square centimeter in area, with a specific gravity of 1.7, which weighs two-thirds of 1700 kilograms for Conclusion I., and weighs 1700 kilograms for Conclusion III. This gives for I., 6667 meters, and for III., 10,000 meters. For the very strongest rocks the above numbers should perhaps be increased by one-fifth, and this gives a maximum of 12,000 meters.

These conclusions do not apply to rock-inclosed, liquid-filled cavities. So far as one can understand the conditions, such cavities might exist at an indefinite depth, or at least to a depth where the liquid and rock may be miscible in all proportions.

The above numbers fall within the various limits—roughly, 2 to 8 miles—assigned for the "level of no strain,"[1] or as it should perhaps be called more properly the level of no lateral stress, and thus make it probable that the lateral stress is less than the vertical stress of gravity. Therefore it is probable that the conditions upon which Conclusion III. are based more nearly represent the truth for the greater part of the earth

[1] *Manual of Geology*, by JAMES D DANA, 4th ed., 1895, pp. 384, 385.

than do those of Conclusion I. However, in mountain-making regions the lateral stress may be so great as to comply with the conditions of Conclusion I., and therefore cavities may close at the minimum depth.

The maximum result reached by the calculation is probably in excess of the truth, for all of the assumptions excepting that concerning the free escape of water are those favorable to requiring a great depth for the closing of cavities. However, it is believed that the result is valuable, because it is certainly large enough, and we may be sure that at depths greater than 12,000 meters no cavities can exist. Also it is reasonably certain that in the weaker rocks cavities are closed much nearer the surface than this. As more accurate data for the solution of the problem become available, it may be possible to obtain reasonably accurate results for the rocks of greatest strength and also for weaker rocks of different kinds. For instance, if the crushing strength of ice be determined for temperatures at and somewhat below zero centigrade, the greatest possible depth to which crevasses in glaciers extend at such temperatures may be readily calculated.

It is highly probable that the very greatly increased plasticity of rocks when saturated with superheated water, due to the rise of temperature with depth, would lead to the closing of the deeper lying crevices by flowage and welding rather than by fracture. If the increase in temperature is 1° C. for 30 meters, at a depth of 10,000 meters, the material would have a temperature of 333° C. above the average temperature of the level where climate produces no influence. To this, in mountain-making regions, would have to be added any increase in temperature due to dynamic action. Under gravity alone rocks at such a depth would be subjected to a vertical pressure of 2550 kilograms per square centimeter. As has been seen, the lateral pressure might be less than this if the rock was not in mountain-making areas and near the level of no lateral stress, or it might be as much or more than this if in mountain-making areas and therefore subjected to great lateral pressure. It is probable that at

such temperatures and pressures even brittle rocks, under these great and very slowing acting forces, when saturated with superheated water, obey the laws of hydrostatics, for plastic solids when strained beyond the limit of elasticity follow the same laws of deformation as do liquids. It is probable that the above considerations should reduce the estimate for the closing of cavities in the strongest rocks to 10,000 meters or less.

It therefore appears highly probable that at a depth of 10,000 meters not only do no crevices permanently exist in the earth, but the rocks are in such a condition that actual welding of the fractured parts would soon take place, supposing fracture to occur.

Such was apparently the case in the deepest lying gneisses and anorthosites of the original Laurentian area, described by Adams.[1] Here in certain areas each of the individual mineral particles is broken into many fragments. No extraneous or infiltrated material is discovered between the granules, and yet the rocks are exceedingly strong and tough, showing in all probability that the broken particles were welded. However, there may possibly be a zone in which the deformation occurs by minute fractures of the individual particles, these being held together without interspaces, and yet where the temperature and pressure are not sufficient to cause welding.

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The conclusions as to the depth at which cavities close accord well with observations in the field and with the microscope. It is only in material from the cores of great mountain masses or in regions subjected to vast denudation that the microscope is unable to discover crevices caused by great deformation. The large secondary cracks and crevices which may have formed during the time when the rocks were nearing the surface by denudation are not here referred to, but the innumerable minute crevices affecting the individual grains, which were plainly produced by the deep-seated deformation of the rock. In many instances in which such crevices are found it appears probable from the geology of the region that the rocks were buried under

[1] A Further Contribution to our Knowledge of the Laurentian, by FRANK D. ADAMS. Am. Jour. Sci. (3), Vol. L., 1895, pp. 62, 63.

well-nigh 10,000 meters of material, although this is difficult to demonstrate.

Whether rocks flow or fracture is in many cases largely dependent on the rapidity of deformation. As pointed out by Professor Hoskins, a rock under a certain pressure in two directions, when rapidly deformed by a greater pressure in a third direction, may be fractured, and when less rapidly deformed may flow. This results from the fact that the elastic limit of a rock is always less than its ultimate strength. During the time of rapid deformation the rock may be fractured and crevices and cracks formed which are subsequently closed by plastic flow even if the stresses decrease in amount. Also, as the stresses were slowly increasing, there may have been very considerable flowage before any fractures were produced. Hence, even in homogeneous rocks, the zone of fracture and the zone of flowage are not sharply separated from each other, and the upper part of the zone of flowage is at different depths under varying conditions of stress. This principle is illustrated by the distortion of rocks in ancient buildings and by slabs of marble suspended by their ends in cemeteries.[1] This latter case shows how important the element of time is in the deformation of rocks, and that, given a sufficient time, a stress much below the ultimate strength may surpass the elastic limit and result in flowage. It thus becomes clear that there may be a very considerable thickness for any given rock in which it may be in the zone of fracture or in the zone of flowage, depending upon the amount of differential stress.

(3) *Rocks buried to such a depth that the weight of the superincumbent strata exceeds their ultimate strength are in the zone of plasticity and flowage.* These are the conditions of folding, for permanent perfect flexure is possible only by flowage of material. It is a contradiction to suppose that cracks and crevices can form under these conditions. Were it possible for an opening to be made in any way, under the hypothesis the rock would

[1] An Illustration of the Flexibility of Limestone, by ARTHUR WINSLOW. Am. Jour. Sci. (3), Vol. XLIII., 1892, pp. 133, 134.

flow toward the opening and close it. All of the rocks concerned are everywhere under compressive stress. The material at any given moment, when deformed, moves from places of great compression to places of less compression. In other words, there is always a tendency for the rocks to approach equilibrium through the forces applied, or to obey the laws of hydrostatics. In order that deformation shall occur, the difference between the greatest and the least stresses must equal or surpass the elastic limit of the rock in question under the conditions in which it exists. In rocks which were bent when so deeply buried that no cracks or crevices could form even temporarily, it is probable that the material flowed to its new position quietly, without shock, under the enormous stress to which it was subjected.[1]

Even if in the zone of flowage, the relative thickness and strength of the members folded will play their part. If the mass were exactly homogeneous it would flow in the direction of least resistance, like a mass of tallow. But the rock masses are heterogeneous, and the alternating layers of different plasticity may retain their individuality, there being no considerable commingling of the materials of one layer with the materials of others. The strong, thick beds will greatly vary the direction of movement of the material at a given place, and thus, as explained by Willis, develop folds of great length and amplitude. On account of their relatively resistant character when bent into anticlines and synclines, the anticlines will be able to carry part of the superincumbent load, and thus relieve to some extent the softer beds below, which however, as a consequence, promptly flow in the direction of relief or least resistance and ever press against the confining arch, and thus do their part, which may be the major part, of carrying the superincumbent load. In a similar manner

[1] The manner of the molecular rearrangement by which flowage is accomplished will not here be discussed. In some cases of extreme deformation the granulation or even the recrystallization of the rock is complete. In intermediate cases strain effects are usually marked. For the present purposes we are concerned with the larger deformation of the rock masses. Even were the deformation accomplished wholly by minute fractures without crevices, the deformation in mass, would appear to be that of a plastic body.

the strong formations bent into synclines because of the thrust transmitted along their limbs furnished in part by the weight carried by the adjacent anticlines, will give increased pressure to the softer beds below and add to the ordinary thrust which is already forcing the material to follow the arches of the adjacent anticlines. However, if the superincumbent strata be but sufficient, the strongest and most brittle rock beds, such as quartzite and jaspilite, may be crumpled or bent upon themselves within their own radius without macroscopic sign of crevice or fracture. In extreme cases the microscope is unable to detect any evidence of crevices or cracks, but it shows in a most remarkable manner that the mineral particles have been greatly flattened.

The thinner and softer the beds the less potent are they to control the movement of any considerable amount of material. Therefore, under given conditions, the thinner and softer the beds the shorter and the steeper are the folds, and more nearly does their material approach in its movement to the flowage of tallow. In soft homogeneous shales the approximation is closest. Therefore, in a series or group of beds of different lithological characters, the thick, strong beds are less closely folded than the thin, weak beds. The softer layers are greatly thickened here and greatly thinned there, as demanded by the stronger layers. The folding of the first may be comparatively simple, and the second may be closely plicated. These principles are finely illustrated in the Hiwassee section of the Ocoee series of the southern Appalachians.

In any great anticlinorium, even if the strongest rock be at the bottom — for instance, a massif of granite — it yields to the force of thrust under the law of normal plastic flow, moving toward the places of least compression, and ever presses against and helps to raise and support the overlying arch of sedimentary and other rock. If a massif were absolutely homogeneous without reference to its strength, its movements would be analogous to that of wax. Consequent upon such movement, as explained in a subsequent paper, it is believed that uniform cleavage is often produced. But no massif is homogeneous. It is composed of

mineral particles of different kinds and of different sizes. In a larger way it is composed of rock masses of different characters. Frequently these masses of different characters and strength are divided by vertical or steeply inclined planes of weakness, rather than horizontal ones, as in the sedimentary rocks; hence, major movements take place along the major inclined planes and minor movements along minor planes and between the mineral particles. Complex minor folding and shearing therefore occur in the readjustment of a massif to its new position. The major planes of shearing may be called fault planes, but they differ from ordinary faults in that the parts moved over one another are always in close contact, and probably are also always welded.

When a set of rock beds are bent even slightly, readjustment and rearrangment of the material must occur to some extent, and the amount increases in proportion as the rocks are closely folded.

If a steel bar be bent the molecules are separated to some extent upon the convex side and compressed upon the concave side. When released from stress the bar, by virtue of elasticity, springs back to its original position. While to some slight degree rocks are elastic when subjected to forces continuing for a short time, it may be doubted whether this property is of importance in considering the slowly acting and long-continued forces of rock folding, except perhaps in the slight flexures of great extent. Single rock beds, when much deformed, are rather to be compared to a wrought-iron bar, which when bent takes a permanent set. In this case there is an actual flowage of material or rearrangement of the particles to meet the new conditions. The half of the bar on the convex side subjected to tension is lengthened, and, to compensate, it is of less cross-section then originally. The half of the bar on the concave side subjected to compression is shortened, and, to compensate, it is of greater cross-section than originally. Each homogeneous rock stratum when bent acts like the iron bar to a certain extent. There is rearrangement of its material to new positions, and when the bending occurs without fracture the movements of the rock particles may be like those of the par-

ticles of the compressed part of the iron bar. But rock beds are usually composed of different mineral constituents, which differ from one another in strength, in hardness, in brittleness, in elasticity, and in size. The necessary rearrangement of the mineral particles more largely affects the weak, small particles than the large, strong ones. However, as shown by microscopical study, where a district is closely folded, no particle of a rock stratum, small or great, simple or complex, weak or strong,

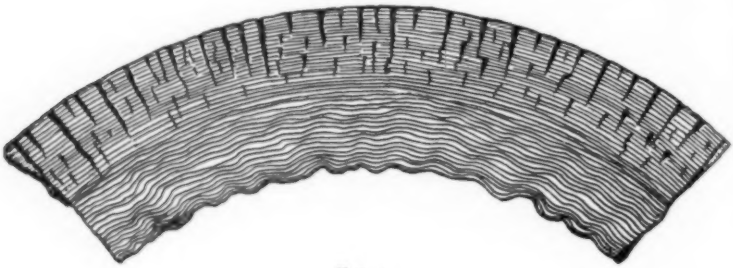

FIG. 1.

escapes the effects of, or fails to take part in, the necessary readjustment of folding.

If a rock stratum could be bent without fracture in such a position that the superincumbent weight were slight, about one-half of the bed, like the iron bar, would be elongated, and the other half would be compressed. Between the two there would be a neutral plane.

As rock beds are brittle they act differently from an iron bar when bent to any considerable degree. Beginning at the middle of the mass in the trough or crest of the fold and passing toward the convex surface, the first lamina is under tension, the second under greater tension, and so on, each stratum being stretched more than the preceding. The tensile force may go beyond the limit of elasticity and radial cracks be formed. (Fig. 1.) Beginning again at the center and passing toward the concave surface, the first layer is under compression, the second under greater compression, and so on, each stratum being more severely squeezed

than the preceding. This may go beyond the limit of elasticity and produce minor plications.

But the majority of strata which have been closely folded when bent were deeply buried beneath other strata. If the superincumbent weight was greater than the strength of the rock all parts of it were under compression, increasing, it is true, from top to bottom in an anticline, and if the mass is not too thick from bottom to top in a syncline. In this case there was no

FIG. 2.

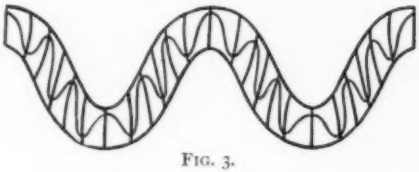

FIG. 3.

neutral plane. The rearrangements which took place were therefore those of varying compression,—flowage away from the places of greatest compression and flowage toward the places of least compression. The crenulations in an anticline may mean that the part of the fold seen was in the compressed area, the stretched and fractured part being removed by erosion. Where both the anticlines and synclines show plications throughout, it follows that the superincumbent strata were so thick that no zone of stretching could be formed, the weight being beyond the supporting strength of the rocks, and the movements being those of a heterogeneous plastic body.

Just as there is rearrangement of the particles within a bed, so there is readjustment of the beds over one another. This may be illustrated by a bunch of paper. (Figs. 2 and 3.) If straight lines be drawn at the edges of a bunch of horizontal sheets, and then the whole be bent into folds, it will be found that the straight lines become curved. In other words, the sheets were moved over one another. An examination of the curved lines

shows that on opposite sides of an anticline or syncline the movement for any given stratum is in opposite directions. Therefore at the anticlines and synclines the forces are directly opposed and hence the stretching or plications at these places, as already explained. But on the limbs of the folds the forces are in the same direction for each lamina, but in opposite directions for laminæ upon opposite sides of any layer, thus constituting a couple. Each stratum moves up as compared with the one next below it, and each stratum moves down as compared with the one next above it. In the case of much inclined and overturned folds this statement needs modification.

The axial lines also show that on the crests of the anticlines and in the troughs of the synclines there was comparatively little movement, while at the middle of the limbs of the folds movements were at a maximum. From this experiment and from Figs. 4 and 5 we would expect that in folded rock strata the effects of readjustment would be least at the crests of the anticlines and troughs of the synclines and most at the middle of the limbs, and such are the facts. In a subsequent article it will be seen that clastic rocks become crystalline in proportion to the degree of shearing and the intensity of the pressure. The former is at a maximum on the limbs of folds and at a minimum on the crests and troughs. Further, secondary structures may develop on the limbs nearly parallel to the beds, while upon the anticlines and synclines the secondary structures form across the beds. It follows that on the anticlines and synclines, where there is most crenulation and puckering of the laminæ, the original structures are less altered, and the clastic characters in sediments, such as sandstones and conglomerates, are likely to be preserved. Upon the other hand, upon the limbs of the folds the obliteration of fragmental characters may be complete. We therefore have the paradox that where there is most crenulation there is least metamorphism; where least crenulation, most metamorphism. This of course applies only to the different positions of the rock in a fold, not to a gently folded district as compared with a more closely folded area.

But the rock beds as they occur in nature differ from the bunch of paper in that they are of varying thickness and strength. The major readjustments of the rock beds occur between the thick and strong strata, and within the weak and soft strata. In these latter, therefore, the rearrangement of the particles is far more profound than would be the case if such beds were folded alone. In closely folded districts among other evidence of readjustments the polishing effects of accommodation between the beds may always be seen in the slickensided surfaces of the major and stronger beds, and in cases of complicated folding the same phenomena are observable between the thinnest laminæ. A most striking instance of this polishing is seen in the Jura Mountains, where at many places both sides of the strong, thick layers of Jurassic limestone are polished as smoothly as if glaciated. They reflect the sun like an imperfect mirror. At some places where the folds are steep, layers have fallen down along these movement planes, exposing great surfaces of beautifully polished rock. In the folded Cambrian quartzites of Doe River, Tennessee, the polishing of the layers by accommodation is scarcely less strikingly illustrated.

If a given bed in the center of a rock formation be plicated and the layers above and below be folded in a strictly parallel manner, in passing away from the central bed in either direction those on either side are less closely folded, and finally the crenulations become slight. If the folds are close in the center they die out with great rapidity. The above follows directly from the laws of deformation of solid masses, and is illustrated by Fig. 4. It should be observed that the more crenulated lines are longer than the less crenulated ones. In so far as this is imitated in nature this implies that there is differential movement between the layers, for originally all of the beds must be supposed to have been of the same length. Such differential motion doubtless does occur in strata in which the folds differ in character, for the more closely folded beds must be subjected to severer thrusts or have been originally weaker, so that the thrust is more effective, or have been in a position in

which friction gave less resisting power. The ideal figure probably more nearly illustrates the effects of nature in passing downward from the central line than in passing upward, for the deformation in superficial strata may be accomplished by jointing, faulting, and brecciation.

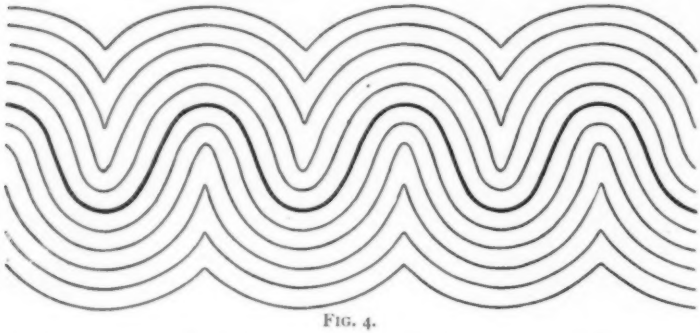

FIG. 4.

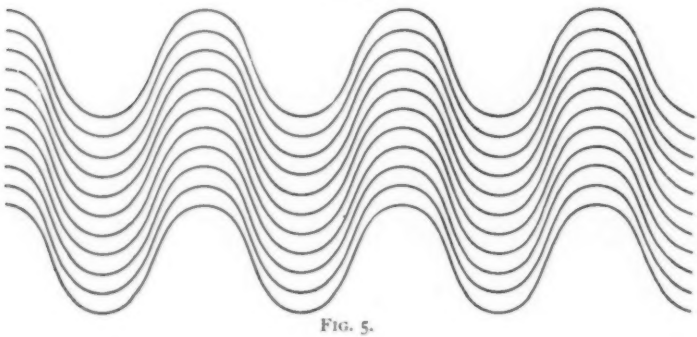

FIG. 5.

If beds above and below the central one be folded in a similar fashion, the limbs of the different layers will be closely pressed together or thinned, or both, and at the anticlines and synclines there will be spaces between the layers, or thickening, or both (Fig. 5). But this result can only be accomplished by plastic flow of the material of the limbs toward the areas of relief. This often produces minor plications at the crests and troughs. Even where the folding is only moderately close the limbs of folds

may be only one-half as thick as the troughs and crests. Where the folding is very close the troughs and crests must be several times as thick as the limbs in order that they may have similar forms.

It is evident from the above that close folds can persist in depth with similar forms only by great differential movement of material, for the readjustment will only go so far as demanded by the differential stresses. It is therefore to be expected that the close folds of mountain districts die out rapidly with increasing depth. This would certainly be true if the lateral stresses diminish, as they must do if the theory of "level of no strain" at very moderate depth be correct. The foregoing doubtless partly explains the open folding often observed in the center of the mountain masses as contrasted with the closely folded flanks, although in many cases other causes undoubtedly enter.

This rapid disappearance of folds with increased depth is beautifully illustrated in a section along the Schuylkill River near Philadelphia, between Lafayette and Spring Mill, shown me by Miss Florence Bascom. In the center of the section is gently undulating gneiss. In passing toward the outer part of the gneiss it is closely folded. The gneiss is flanked on either side by still more closely folded mica-schist. Not only is the principle illustrated by the entire section, but at various places close local folds may be seen, above and below which the folds rapidly become more open. The same is illustrated in the crumpled gneisses of the Ottawa River. The same principle is illustrated upon a much larger scale by the section along the Doe River west from Cranberry, N. C. The folding and the schistosity of the pre-Cambrian granitoid gneisses are gently composite, while the overlying Palæozoic quartzite shows many close minor folds. This case is a particularly good one, for it can hardly be supposed that the quartzite is much less rigid than the gneissoid granite.

It follows from the above that where different beds are in folds of similar forms rearrangement within the beds, adjustment between the beds, and distortion of the beds all work together

to shear the limbs of the folds parallel to the bedding and to develop plications in the crowns and troughs.

(2) *Since the boundary between the zone of fracture and the zone of flowage is at a different depth for two rocks of unequal strength, and for the same rock under different conditions of stress, there is a zone of combined fracture and flowage.* In a set of heterogeneous beds upper weak strata may be in the zone of folding, while lower and stronger strata may be in the zone of fracture. Also, as pointed out by Willis, if strong folded strata at anticlines are competent to carry much of the load, as they often are if the arches are not too long, weaker strata below may be so relieved from weight as to be partly deformed by fracture. Thus between the horizon where all the rocks of a district fracture, notwithstanding the weight of the superincumbent beds and the horizon where the effective weight of the superincumbent beds, is so great that no rock fractures is a zone of combined folding and fracturing. This central zone is one of great thickness, and is of the first importance.

A soft shale may be in the zone of folding, far above a strong quartzite or jaspilite, and the latter be in the zone of partial deformation by fracture. This difference in strength is at many places certainly equal to the weight of 2000 or 3000 meters of strata, and is probably equal to the weight of 5000 or more meters of strata. Thus this middle zone is probably at least 5000 meters thick, and it may be considerably thicker than this.

In heterogeneous rock strata in this middle zone, irregular fracturing, brecciation, jointing, faulting, folding and the development of secondary structure may occur together in a most complex manner. A deeply buried, brittle formation may be under such stress that as a whole it folds without major fracturing, but in a minor way it may be faulted, fractured, or brecciated. The fracturing may leave no permanent openings, as the softer material may promptly flow and fill the openings between the more brittle broken layers. Such is the case in the jaspilite beds of the Lower Marquette series of Michigan. Such is also the case at many places where beds of shale or limestone

are interstratified with beds of grit or sandstone. The first may pass to its new position by homogeneous flow, the second by repeated fractures, which in extreme cases may break the harder beds into fragments and bury them in the softer rocks. The same relations often are seen between mobile marble and brittle gneiss. Whether fracturing always implies at least temporary crevices is an undetermined point.

The weight of the superincumbent material may have been so great that the rock beds as a whole bent without macroscopic fracture, and yet the microscope may show that the individual grains were broken and that minute crevices were formed which have been subsequently filled by secondary infiltrations. At many places the massive beds the quartzites of Doe River, Tennessee, are bent upon themselves within their own radius, with no macroscopic evidence of crevice or fracture. But the microscope shows that the fracturing and resultant flattening of the quartz grains was almost universal.

This illustration shows that for a given kind of rock the zone of fracture passes gradually into the zone of flowage. Even where so deeply buried that all large fractures are absent and the rocks are practically in the zone of flowage, the microscope may still show crevices. It has already been indicated that the zone of flowage is much deeper for some rocks than for others. Also for the same rock mass it may be less deep when gently folded than when closely folded. It is therefore clear that there are gradations between the three zones—of fracturing, of fracturing and flowage, and of flowage. In the placing of a rock mass in one of the three zones it is to be considered as belonging to the one to which it most closely corresponds. If the rocks are everywhere broken and show comparatively little folding, they are in the zone of fracture; if they show much fracturing and also are folded, they are in the zone of fracture and flowage; if the fractures are subordinate or microscopic, they are in the zone of flowage.

C. R. VanHise.

EDITORIAL.

A CARD recently sent out by the director of the United States Geological Survey contains this announcement: "The following provision was included in an act of congress, approved March 2, 1895: '*Provided*, That hereafter the report of the mineral resources of the United States shall be issued as a part of the report of the director of the Geological Survey.'"

This change in the form of the mineral resources serves as an excuse for some reflections upon the subject of the sizes of geological publications in general. It is to be presumed that the reasons for changing the form of this particular publication are good and sufficient: this is not questioned; and the specific mention of these books must not be regarded as personal, but simply as illustrations of what we believe to be a general principle, applicable to all, or nearly all, geological literature alike. It may be added that the forms of all the publications of the United States Geological Survey are prescribed by statute, and the determination of their sizes is not an individual function of the director.

Our plea is for smaller books. We look upon bookmaking, not as an end or an art, but simply as a means—as a method of recording and conveying information. From the point of view of the bookmaker and the book fancier this may be all wrong, and the rankest of Philistinism for anything we know, but with their view of the matter we have but little to do. No doubt the sizes of books on geology as upon other subjects have been handed down to us. Parkinson's *Organic Remains*, published in three volumes from 1804 to 1811, and Buckland's *Reliquæ Diluvianæ*, were quartos printed in "English"—the size larger than pica. The *Transactions of the Geological Society of London*, the first volume of which was published in 1811, were big quartos. Murchi-

son's *Silurian System*, published in 1839, was even larger, as was also his *Geology of Russia* published in 1845. These publications set the pace, as it were, for books of pretension.

In those days no one thought of taking a book on geology into the field with him—they were for use in the library or the laboratory. Nowadays many, probably most, working geologists, mining engineers, consulting geologists, students and instructors, not to mention miners and prospectors, carry, or want to carry, books with them in the field. To all such persons the size of the book to be carried is a matter of importance, and especially so on long or difficult trips when baggage must be light. To them these bungling big volumes, these ponderous tomes, are simply out of the question. And we are of the opinion that the carrying of books into the field ought to be encouraged, and that their being printed in octavo will encourage it and will, at the same time, increase their usefulness and widen their influence.

If the big quartos had any more in them to the page than the octavos they would have that advantage at least, but they do not as a rule. Take for example the annual reports or the monographs of the Geological Survey. The latter are printed in pica, so they contain no more to the page than octavo pages would in long primer. The annual reports are printed in the same type (long primer) and the pages are the same size as those of the bulletin (7.4″ x 4.4″ solid) and the only difference between them is that the heavy annual reports are made quartos by being printed on heavy paper with wide margins.

Compare the weights of the annual reports and the bulletins: Bulletin 71 (octavo), with 744 pages, bound in cloth, weighs two pounds, ten ounces; the ninth annual report, a quarto of 731 pages, weighs seven pounds, six ounces. In other words, the bulletin weighs less than half as much as the annual reports, page for page.

The following advantages are claimed for the large volumes:

1. They admit of large page plates of fossils, maps, or other illustrations, which are not possible with octavos.

We reply: There is no denying that a map or plate shows

to its best advantage when lying open, flat, and unwrinkled. But the single page plates of the quartos can easily, in many cases, be folded across the middle and tipped in, without in the least diminishing their value to those who use the books. In other cases, of small fossils, for example, plates can just as well be made of smaller size. The gain by decrease in the size of the volume far outweighs any inconvenience arising from the folding of maps or plates.

2. When printed on good paper the leaves open properly, while in the octavos they are too rigid.

We reply that it is no serious matter to find flexible thin paper on which good printing can be done.

3. Books to be taken into the field can be cut apart so that the parts wanted can be carried without inconvenience.

We reply. The suggestion that one cut up his book comes from those who have as many copies as they may need at their disposal. The private individual who has to pay for the books and maps, or who has much difficulty in getting them, rarely feels like tearing out maps or a dozen pages from his volume because it is wanted in the field on a certain trip. He will either take the whole book along or leave it behind.

4. Big books look better than little ones.

We are not disposed to discuss the looks of books. The question with which we are concerned at present is one of service to geologists and to those who look to us for help. Books made for display—"editions de looks," as Lowell might say, more especially when the form interferes with their usefulness—are not for the serious minded geologist. We do not mean to imply that the appearance of geological books should be altogether disregarded, but simply that their utility should not be sacrificed to the vanity of authors, or to the book's solemn *otium cum dignitate*.

But we go further: We maintain that big books are inconvenient in the library, on account of the room they occupy both upon the shelf and when in use upon the table, and on account of their coming to pieces after a little use. Every

librarian whose cloth-bound quartos are much handled will bear me out in this.

There is no advantage in very large type: it is just as easy to read the long primer used in the bulletins of the United States Geological Survey as it is to read the pica of the monographs.

There is no advantage whatever to a working geologist or to a student for his books to have large pages, wide margins, or to be printed on unnecessarily thick paper. Such books are cumbersome and unwieldly in the library or laboratory without an abundance of table room, and altogether out of the question for the field.

Small books will serve equally well the man in the office or in the field, in camp or on horseback. The taking of books into the field should be encouraged; our laboratory is there, and there is no other place in which a book can render such lively service.

J. C. B.

Reviews.

The Age of the Second Terrace on the Ohio at Brilliant, near Steubenville.—The inquiry raised by Professor Chamberlin, in his comments (Journal of Geology, Vol. IV., pp. 107–112) upon the age of the gravel at Brilliant, Ohio, in which Mr. Huston's discovery of an implement was made, is both pertinent and important, and certainly calls for a more specific statement of my reasons for believing that its deposition was substantially synchronous with that of the 130-foot terrace at the mouth of the Beaver, about fifty miles above it, concerning whose age there is I believe, no question. Of course the only absolute certainty in the case is that at the time of the deposition of the gravel at Brilliant the floods in the Ohio River at that point reached a height something more than eighty feet above the present low-water mark. This the character of the cross-bedding actually demonstrates. The evidence connecting it with the 130-foot terrace at Beaver, while of a more general character, is still, I think, convincing.

In the first place, Professor Chamberlin's remark that there are terraces on the river above and below Brilliant that reach 120 and 130 feet above low water, while the implement-bearing terrace reaches only 80 feet, though literally correct, conveys a false impression without a fuller statement of the facts. The nearest 130-foot terrace above Brilliant is that at Beaver, where a powerful glacial tributary came into the Ohio overloaded with terrace material. From that point down to Brilliant the terrace, though practically continuous on one side or other of the river, gradually diminishes both in height and in coarseness of material, and never rises more than 102 feet above low water until reaching Portsmouth, two or three hundred miles below, where the Muskingum River, the first glacial tributary below Brilliant, joins the Ohio. Here the terrace rises 110 feet, while at Cincinnati, below the junction of the Little Miami, the terrace for the first time jumps again to the 120-foot level. The smaller height of the terrace at Brilliant, therefore, is readily explained without the theory of its having been worked over.

It should be noted, also, that the locality where the implement was found is near the west side of the trough of the river, whose entire width is here fully one mile. This is just one of those positions, therefore, in which we might look for a diminution both in the original height of the terrace and in the coarseness of its material, since all rivers in building up a flood-plain deposit the coarser material near the main current, and consequently build up the plain higher there than on the margins. I see therefore no reason to be shaken in my conviction that the terrace at Brilliant is approximately as old as that of the 130-foot terrace at Beaver, but it is a question to which I trust specific attention will be given by others. G. FREDERICK WRIGHT.

OBERLIN, Ohio, February 15, 1896.

Place is cheerfully given to the foregoing as it is helpful in bringing out more precisely and amply the question of the age of the terrace at Brilliant. It is also helpful in making additionally clear the fact urged in the review, that the age of the terrace is an open question of interpretation rather than a firm conclusion based upon substantial demonstration. The brief statement of the review was unquestionably inadequate, but its defects were, we think, less favorable to the grounds of doubt urged by the reviewer than to the grounds of belief entertained by the author, as will perhaps appear from further consideration of the case.

A rigorous discussion of the question would necessarily be lengthy and would require data as yet undetermined, but a few of the more obvious considerations necessary to a safe interpretation may be briefly indicated.

The view entertained by Professor Wright that the glacial filling would naturally be highest at the mouths of the main streams which came down from the edge of the ice is not an improbable one, though not necessarily the only one. The conception involves a series of sudden rises in the river bottom at the mouths of the tributaries followed by declines below them; in the present case, a rise to 130 feet at the mouth of the Beaver River; a decline down stream to some unknown level below 80 feet; another rise to 110 feet at the mouth of the Muskingum River, a second decline, and again a rise to 120 feet near the mouth of the Little Miami. The case is really more complicated than this, because it involves the deposits of the Scioto, Great Miami and minor streams, but this is immaterial for present purposes.

Now what would be the normal history of a stream bed filled in this rythmical fashion, when the source of special supply was cut off? Obviously erosion must have begun on the crests of the high deposits. The material so eroded must have been carried forward and *deposited in the lower stretches* just as material is now being deposited in the bottom of Lake Pepin, whose existence is attributed to the deposits of the Chippewa River that enters just below it. Clearly the eroded material could not be carried over the next rise until a common degradation gradient for the whole section was established. A period, therefore, followed the close of the glacial action during which the high deposits were cut down and *the low deposits built up*. In the present case the Beaver deposits were presumably cut down and the Brilliant deposits built up.

How long this period continued it is impossible to estimate accurately, for it was dependent on several uncertain conditions. (1) From the very nature of the hypothesis, it is impossible to determine what was the status of filling of the low parts at the close of glacial action. Almost any degree of filling or lack of filling may be assumed. (2) The retarding effects of the Champlain depression are quite unknown. (3) The deposits in the valleys of the glacial tributaries participated in the action to an undetermined degree. As soon as the high deposits at their mouths began to be cut down, their gradients, already high, would be increased and their material would be carried into the main stream and would check further degradation until it was disposed of. It was even possible, under certain conditions, for these tributaries to continue to build up the deposits at their mouths after the cessation of glacial action.

How much the Brilliant terrace was built up during the establishment of a common plane of degradation seems to be quite indeterminable. Taking the present Ohio as a basis of reference, and supposing the surface of the Brilliant terrace to represent the plane of equation (neither of which is beyond question) there were heights of 30 to 50 feet, in addition to the contributions of the tributaries, to be brought down, and the low parts to be built up from unknown depths. The shallow depth of the implement, eight feet, seems a very modest figure to assign as the possible, or even probable, upbuilding of the Brilliant deposits.

There is still another item in the history. After the establishment of the plane had been accomplished, there was a temporary stage of equilibrium in the parts built up, followed by the initial stages of

degradation. In the degradation of such a plane the material is not taken up once for all and carried out to the sea (except of course that held in suspension), but is shifted little by little through cutting here and filling there, until, piece by piece and shift by shift through almost endless repetitions, the material is at length transferred to the sea. The newly formed portions of the equated plane would be liable to suffer this process over their whole surface during the stage of equilibrium and the early stages of degradation. It would be only when the degradation of the portions down stream had increased the gradient to such an extent as to lead to a contraction of the channel and the abandonment of a portion of the flood plane, that reworking of the surface parts would cease.

If, therefore, we assume the style of fluvio-glacial deposition postulated by Professor Wright, we find definite reasons for regarding the upper part of the Brilliant deposit as postglacial in origin, and find moreover special conditions that may have subjected it to reworking during the early stages of degradation that followed its construction. If, on the other hand, we assume that the glacio-fluvial deposits took the form of a common aggradation plane at the close of glacial action, the presumption is that the Brilliant terrace was carved out much later. It is just possible that the Brilliant deposits happened to be at the pivotal point between degradation and filling, and so were original — and the review admitted that they might be — but the more the case is studied the less probable this seems. T. C. C.

North American Fossil Crinoidea Camerata. By CHARLES WACHSMUTH and FRANK SPRINGER. (Memoirs Museum of Comparative Zoölogy.) Two parts, 800 pages, and atlas of 83 plates. Cambridge, 1895.

During the decade just passed our knowledge of ancient organisms has been enormously expanded, not so much through the old grooves of endless multiplication of species, as along lines in which the most recent conceptions of morphological inquiry are taken into consideration; or along lines having a direct bearing upon the interpretation of geological phenomena. Hence the differentiation of modern palæontology has been chiefly in two directions, and these departments are becoming so widely divergent that they will ere long, if some energetic steps are not taken to prevent it, cease to be of mutual aid. The

science as originally inaugurated was the foundation of modern stratigraphical geology; but of recent years the biological interest has developed so rapidly with the vast accumulations of remains of ancient organic life that this branch of the subject bids fair to soon cut loose entirely from the parent stem. No better illustration of this tendency has been shown than at a late gathering of the principal scientific societies of America. Of all the palæontological papers presented at the meetings not a single one was read before the Geological Society; the entire list was discussed at the biological associations.

The impetus given to palæontology in the direction of pure biology is timely, and the delay in entering that field may be ascribed chiefly to lack of sufficient and proper material for satisfactory study. The palæontologists of the new school have taken up the discussion of live organisms and their examination according to the latest and most approved methods in order that the long extinct forms of life might be interpreted more correctly. And the most advanced students of existing beings are beginning to look with less aversion than formerly to the fossils for the missing links for a complete phylogeny and ontogeny of living things. As the result of it all the value of organic remains for solving the intricate problems of the stratigraphic geology will be increased a hundredfold. The exhilarating effects have already begun to be felt in that branch of geological inquiry that was thought to be all but inert.

The life and racial histories of fossil vertebrates have for some time past yielded most beautiful and suggestive results. In the same direction the vastly more extensive groups of the invertebrate has in this country at least received scarcely a thought. Palæontologists therefore will hail with delight the appearance of Wachsmuth and Springer's masterly and exhaustive monograph on the North American camerata the most important branch of the crinoids. While it is first of all morphological from the foundation up, and the product of inquiries more thoroughly grounded in biological philosophy than any other work perhaps that has ever been issued on the fossil invertebrates in this country, it is also of such high utility in stratigraphy, especially in the great Mississippi basin, that it may be truly said no other one work has ever furnished so valuable criteria for the purposes of correct correlation of geological formations.

Of all fossil remains none are more admirably adapted for morphological study than those of the echinoderms. On account of their

abundance, their peculiarities in geographic and geologic distribution, and their structure, the stalked feather stars or stone-lilies are preëminent. With the skeletal parts composed of regular plates or ossicles, definitely grouped and frequently highly sculptured, all structural changes are readily deciphered.

The work on the crinoids is the outgrowth of studies begun more than twenty years ago, under the encouragement of Louis Agassiz, and prosecuted without intermission ever since. The entire work as contemplated will form two huge quarto volumes, of which the first, in two parts with an atlas of plates, has just been issued. Of the text there are nearly 800 pages; and the plates number 83, comprising 1500 illustrations artistically reproduced as photogravures. In the present installment—the Crinoidea Camerata—there are three main subdivisions; introductory, morphological and descriptive.

The introduction embraces an historical résumé of opinion and a full explanation of the terminology employed in description. Special attention should be called to the clear and concise definitions given of the various structural parts. The terms should be universally adopted as they form by far the best collection ever proposed. American writers especially will need no appeal to at once use them not only to secure uniformity in nomenclature but precision of description. Heretofore the names of the various plates or groups of ossicles have been used in a rather haphazard way. Not only have different designations been given to the same part, but the same title has been repeatedly applied to structures widely separated morphologically.

The morphological part contains the full discussion of the data upon which the entire classification of the crinoids rest, of the genetic relationships of the various groups, and of the structural characteristics.

The plates in general are separated into "Primary" and "Supplementary" pieces. The former occur in every crinoid and comprise the ossicles represented in the early larva, the basals, the infrabasals, the various plates of the rays or arms, the orals, and the joints of the stem. The supplementary pieces, which make their appearance in the more advanced stages, but which are altogether unrepresented in some groups, comprise the remaining plates. The primary ossicles belong either to the "abactinal" or to the "actinal" system. Those of the former including all the plates, connected with the chambered organ and axial cords; the others comprising those communicating with the mouth and the annular vessels surrounding it.

The stem is much more important than generally considered. It is composed of *nodal* and *internodal* joints, and continually increases in length in the growing crinoid by the production of new joints. The nodal plates in the Inadunata, Camerata, and a few of the Mesozoic and recent crinoids, are introduced directly beneath the proximal plate of the calyx, so that the uppermost joint for the time being, is the youngest joint of the stem. In the young Comatula, however, in which the top joint subsequently develops into a controversal, in the Mesozoic Millerocrinus and Apiocrinus, in the recent Rhizocrinus and Calamocrinus, and in all Ichthyocrinidae, forms in which the top joint in the early larva anchylose with the infrabasals, the new nodals are introduced below the top joint. The internodals are interposed between the nodal joints and increase continually in a downward direction during the life of the organisms *pari passu* with the formation of new nodal pieces. The stem matures from the root up, and remains permanently in a state of immaturity at its upper end. The maximum number of internodal joints varies among different forms. Sometimes there are many to the internode, as in the case of most species of Platycrinus, in Mespilocrinus and Rhizocrinus: sometimes only a very few; while Rhodocrinus, throughout its stem generally, has but one.

The cirri in Palæozoic crinoids are, as a rule, more formidable than in later forms, and in most of them they are confined to the lower part of the stem, often occurring only at the distal end. They are given off from the nodal joints, and are generally arranged singly, rarely in whorls as in recent forms.

It has been the general opinion that all Palæocrinoids are fixed forms, but this view is not now believed to be true. The facts appear to lead to the conclusion that at least many of the species in the later part of life were free for a portion of the time, as in the case of the recent Pentacrinidæ, in which the stem at some time at or near the maturity becomes separated from the root. The terminal end in most of the old crinoids tapers to a sharp point, but a root is rarely attached, while detached roots are found abundantly, but scarcely ever associated in the same stratum with the crown.

The real morphological relations of the Basals and Infrabasals is of particular interest. The latter term is adopted for the first plates in the base, and "basals" for the circlet next to radials. The basals of dicyclic crinoids always consist of five pieces; the infrabasals of five, rarely three. In monocyclic forms the base is divided into five, four,

three and two pieces, or all five plates may be anchylosed, so as to form a single piece. Among the Camerata five basals are restricted to the Lower Silurian forms, four basals to those from the Upper Silurian and Devonian, three to those from Upper Silurian to the Lower Carboniferous, and two in only some forms from the Carboniferous. The diminution in number takes place in geological succession, and is the result of fusion of two or more of the original five plates, as is clearly seen in genera without an anal plate between the radials. In forms, however, in which an anal plate is represented and the basal disk is consequently changed from a pentagonal to hexagonal shape the case is somewhat more complicated, for a bisection of the plates in the hexagonal base would produce six basals instead of five. The introduction of the anal among all the monocyclic groups is accompanied with an increase in the size of one of the basals, there being no special basi-anal plate. In the tripartite base, the smaller plate — always the left antero-lateral one — doubles its size. In the quadripartite base the increase is towards the right of the posterior plate; while in the bisected base in which the left postero-lateral basal, the antero-lateral, and the anterior one are fused, the two plates of the opposite side increase in size so as to correspond with the compound plate to the left. In dicyclic crinoids the introduction of the anal does not affect the arrangement of the infrabasals, and only slightly the form of the basals. In species with three infrabasals, one of the plates is always only one-half the size of the other two. This ossicle is, in the Ichthyocrinidæ and comatula larva directed toward the right posterior radial; but in the Inadunata its position is not constant. The basals of dicyclic crinoids are but little affected by the presence of the anal, only the upper angle of the posterior plate being slightly truncated.

When it was discovered several years ago, by Wachsmuth and Springer that among Palæocrinidæ there is a regular alternation of the successive parts below the radials it was also found that the orientation of the stem in the monocyclic groups is reversed in dicyclic forms. In the former the sharp outer angles of the stem are radial; in the latter interradial. The central canal and the cirri are interradial in the first mentioned forms, but radial in others. The law is, however, applicable to its full extent only in species with pentangular or pentapartite stems, but it is concluded from analogy that the circular stem, wherever it occurs is also practically interradial in dicyclic crinoids and radial in monocyclic ones. However, on applying the rule to mesozoic and later

crinoidæ it appears that in most of the so-called monocyclic forms, the orientation of the stem, central canal, and cirri agrees with the dicyclic type, the infrabasals being succeeded by a radial stem, as in those crinoids in which these plates are present but too small to be visible on account of being completely covered by the upper stem joint. Upon the strength of these observations, partly, these authors suggested that such forms either had small infrabasals hidden beneath the top stem joint, or those pieces had been represented in the larva. Other observations led to the same conclusion. In Extracrinus and in two species of Millericrinus, the former belonging to the Pentacrinidæ, the latter to the Apiocrinidæ, two of the principal families of the Pseudomonocyclia, small infrabasals actually exist, and it appears very improbable that those plates should be present in genera of the same family, and even among species of the same genus, and absent in others, especially when the space which in some of them is occupied by small infrabasals, is vacant in others, and interradially disposed instead of radially as it would be if the space represented the axial canal. On applying these observations to the Comatulæ it was found that the outer angles of the top stem joint in the Pentacrinoid larva of the Antedon, and the angles of the centrodorsal in the mature animal, did not come under the rules laid down for the Monocyclica, and this led to the conclusion that the Comatulæ also were built upon the dicyclic plan, and had infrabasals in early life. The predictions, which had been based exclusively upon palæontological evidence were afterwards verified by the observations of Bury, who actually found infrabasals in the ciliated larva of Antedon. They consist of three unequal pieces, which in the Pentacrinoid stage are fused together with the top joint, so as to form with the latter one large plate with the five angles radial in position. A similar fusion evidently takes place among palæozoic Ichthyocrinidæ, in which the infrabasals are also coalesced with the upper stem joint, as is shown by specimens in which the stem is detached from the crown. These individuals are in the same condition morphologically, as the two species of Millericrinus figured by de Loriol, in which the infrabasals coalesce with the stem contrary to the other species of that genus, and allied forms having the infrabasals more or less completely fused with the top joint. As this structure prevents the formation of new joints directly beneath the calyx, it is contended, from the analogy, that in all forms in which the infrabasals coalesce with the stem, the new stem plates are introduced at some

point beneath the top joint. The case is quite different in the Pentacrinidæ, where the youngest joint for the time being is the upper joint of the stem. Of the genera referred to this family, Extracrinus has small infrabasals persistent through life; while in Pentacrinus and Metacrinus no trace of these plates can be found in the adult; their stems are disposed interradially as in Extracrinus and other true dicyclic forms. That the plates are fused with the upper stem joint, is scarcely possible, as it would prevent the formation of new joints at the top; it is more probable as indicated by palæontological evidence that the infrabasals within the group, gradually diminished in size, and finally disappeared altogether. The structure of the Pentacrinidæ in this respect is very different from that of the Apiocrinidæ and Comatulæ, and it appears that crinoids in which the upper stem joint is the youngest, cannot be derived from types in which the upper joint is fused with the infrabasals. The latter therefore should be placed near the Ichythyocrinidæ and the Pentacrinidæ with, or close to the Inadunata.

These generalizations, so far as now known, meet with but two exceptions: the axial canal in the stem of Pentacrinus, contrary to that of Metacrinus and Extracrinus is interradially disposed; that of the monocyclic *Glyptocrinus fornshelli*, unlike that of the other species of the same genus, radially, so that the direction of the canals corresponds with the angles of the stem instead of alternating with them. This however does not invalidate the law, but simply points to the existence of the transition forms between the monocyclica and the dicyclica, as must have occurred at some time in the developmental history of the two groups if the one was evolved from the other.

The radials are less complicated in their morphological relations than the plates which they succeed. The term is now restricted to the first plate of each ray; and all succeeding pieces in a radial direction, whether free or incorporated into the calyx, are called brachials. In the earlier Inadunata and articulata but not in the Camerata so far as observed, the radials are frequently compound, being constructed of two segments, united by a horizontal suture, which in the organization of the crinoid corresponds to one plate. In most of the genera having compound radials the double ossicles, the two sections of which are called "infraradial" and "superradial," are confined to the right posterior ray, but they occur also in other rays but never in more than three, two of the radials at least being simple.

Recognizing the radials as practically a single plate in each ray, all plates above must be regarded as brachials to which pinnules may be attached. The terms costals, distichals and palmars are appropriately applied to the first, second and third orders of brachials respectively. When there are further divisions in the rays, the plates are designated as postpalmars, or as brachials of the fourth and fifth orders, and so on. A discrimination is also made between fixed and free brachials, the latter often being termed the arms. The arms are composed of one or two rows of plates. All biserial arms are uniserial in the young crinoid and gradually enter the biserial stage by an interlocking of the joints from opposite sides. In most of the families belonging to the Camerata the uniserial type is restricted to the Silurian, except in Hexacrinitæ. Among the Inadunata biserial arms occur only in a few genera found in the Kaskaskia, in the Coal Measures and in the Trias, but associated with the forms having the uniserial type. All Articulata, palæozoic as well as neozoic have uniserial brachial appendages.

The pinnules in a general way are repetitions of the arms on a small scale. When represented they spring alternately on opposite sides from every second joint and every joint bears a pinnule except in cases of a syzygy, in which the syzygyial plates must be counted in the alternation of the pinnules as one ossicle. Syzygies occur among Palæozoic crinoids either in successive series throughout the arm, as in the Heterocrinidæ and Belemnocrinidæ, or there is but one syzygy to each order of brachials, formed by the two proximal plates, as in Poteriocrinus, Dichocrinus, and in most species of Platycrinus. In Dichocrinus the various orders of brachials to the last axillary consist of two plates each, the first non-pinnulate, the upper bearing an arm instead of a pinnule. A similar arrangement occurs above the costals in most species of Platycrinus and it is quite evident that the plates in question, as in Dichocrinus for example, do form a syzygy. This, however, is not the case is such forms as *Platycrinus huntsvillæ* and a few other species. Here the first pinnule is given off from the proximal distichal, and the second on the same side from the first palmar. It shows clearly that the arm partakes of the alternation of the pinnules, and suggests that the armlets are enlarged pinnules. This is shown more conclusively by the structure of *Glyptocrinus dyeri*. While in most species of Glyptocrinus the second bifurcation takes place from the second distichial, that plate in *G. dyeri* gives off in place of an arm a large pinnule, more than twice as large as an ordinary one, which bending outward

forms an angle as in the case of a true bifurcation. The second pinnule, which is somewhat smaller starts off from the fourth distichial on the opposite side as in the other species of the genus. All succeeding pinnules are small, and are given off alternately from successive joints.

The oral plates have been the subject of much controversy, but their identification in the different groups is now pretty well established. According to Wachsmuth and Springer the orals are not always represented in the adult. When present they surround the mouth or cover it. They may occupy the whole face of the ventral disk or only its median portion. In the former case they rest upon the edges of the radials; in the latter against the perisome. In crinoids with a regular pentamerous symmetry they consist of five pieces interradially disposed, and form the center of the disk. When the symmetry is irregular they are pushed more or less to the anterior side. The former condition prevails among recent crinoids; the latter is the general rule among palæozoic forms. When asymmetrical, the posterior oral by the encroachment of the anal plates, is pushed between the four others, so as to attain a more or less central position. The plate is generally larger than the other four. The orals in all groups in which they are represented consist of five pieces. There is no such thing as an orocentral plate, as some writers have supposed. In some instances the orals seem to be wholly or partly resorbed; the former condition probbly is the case among the Camerata, the latter in certain species of the Fistulata. In regard to the Ambulacra it is now generally admitted that the aperture in the tegmen of palæozoic crinoids is not the oral opening but the anus, and the mouth is subtegminal forming the center of radiation, which, however, is not necessarily the geometrical center. The ambulacra follow the grooves along the ventral side of the arms, and extend from the tips of the pinnules to the mouth. Their inner ends are either exposed upon the disk, or covered wholly or in part by plates of the tegmen. The upper face of the ambulacra is occupied by the food grooves, which are roofed over by the covering plates and frequently are boarded by side pieces. In recent crinoids the covering plates are movable from the tips of the pinnules to the entrance to the mouth; but in most palæozoic ones those of the disk are rigid, so far as known, often heavier, and larger than the intervening plates. The disk portions of the ambulacra in the Camerata, if tegminal form a component part of the tegmen, their plates being suturally connected with one another and with surrounding plates; those

in the Fistulata rest upon the edges of large interradial pieces. When the ambulacra are subtegminal they enter the calyx by the arm openings, and follow the inner floor to the proximity of the mouth.

The "supplementary plates" comprise all calcareous particles between the basals and orals, and between the rays and their subdivisions. They are interradial, interaxillary or anal. The interradial plates which are separated into interbrachials and interambulacrals, comprise all pieces between the basals and orals interradially disposed, the former being confined to the dorsal cup; the interambulacrals occupy only the spaces between the ambulacra. The interaxillaries, which consist of the interdistichals and interpalmers are located within the axils of the second and third orders of brachials respectively. The anal plates are restricted to the posterior interradial area, and support the anal tube. Another system of supplementary plates occurs in the acrocrinidæ, between the basals and radials. In groups in which the arms are not entirely free from above the radials, the lower arm plates are incorporated into the calyx by means of interbrachials; and the orals are carried inward toward the actinal center by interambulacrals. The supplementary plates increase in number in the growing crinoid. They are undeveloped in the early larva and in the Laviformiæ. In the Fistulata they are represented only in the tegmen, except in the case of the anal piece. The plates vary exceedingly in form and character, being in some groups well developed and rigid, in others irregular and imperfectly formed or mere lime particles within soft tissues. The great variation in the structure of the plates formerly led to the belief that the rigid and regularly arranged pieces, so characteristic of the Camerata, did not belong to the same system as the irregular small pieces which unite the rays in recent form. A distinction was also made between the ossicles of the tegmen. The heavy, rigid components of the palæozoic forms called "vault" pieces the irregular smaller ones "disk" plates; and it was supposed that many of the older crinoids had a vault with a disk underneath. That they had two integuments was believed to be indicated by the condition of the ambulacra, which in recent crinoids are exposed, while in palæozoic types they are either completely subtegminal, or the food grooves are rigidly closed by immovable covering pieces. This supposition, however, has proved to be an illusion and to be based upon inaccurate observation. Even in species of Batocrinus and Dorycrinus, in which deception seemed to be almost impossible, it is ascertained from excellent material, that the

tegmen consists of but one set of ossicles and that the plates are suturally connected and solid on the outside, but perforated and vesicular within. The condition of the ambulacra in camerate crinoids, whether tegminal or subtegminal, does not represent an essential structural feature, but is a natural consequence of differences in the form and construction of the tegmen in the respective groups and as such cannot be of much value from a morphological or classificatory point of view. Subtegminal ambulacra, as a rule, are most prevalent in species with high dome and bulging arm basis; while forms with a flat or depressed ventral surface generally have tegminal ambulacra. The two styles occur side by side among species of the same genus, and there exist all possible transition forms between the two extremes, *i. e.*, specimens in which the ambulacra are subtegminal at the median portions of the disk, and tegminal near the periphery. By comparing the younger individuals with the older, it appears that the covering of the ambulacra is produced in the growing animal by the gradual extension of the interambulacral areas along the lines of the ambulacra, either completely covering them, or leaving the portions next to the arm basis exposed. The ambulacra of the Camerata, therefore, are covered not by an element unrepresented in other groups, but by small superimposed plates passing out from the disk proper. These plates were quite small in the Silurian species, but change essentially until in the Carboniferous they frequently attain the large size and rigidness of the other plates in the tegmen. As to the closure of the mouth, it is now believed that it was subsequent to the introduction of the anal plate, by means of which the posterior oral was pushed in between the four others so as to close the opening.

The interbrachials and interambulacrals, in most of the Camerata, pass insensibly into one another, there being no line of demarkation by which they may be separated, except that produced by the arms, and it is difficult to understand how these plates can be distinct structures as is generally supposed. That their morphological relations are very close is conclusively shown by the fact that the very same plates which in the Actinocrinidæ and Batocrinidæ are strictly interbrachial, are in the Platycrinidæ and Hexacrindidæ partly interbrachial and partly interambulacral, and in the Cyathocrinidæ exclusively interambulacral. That the plates of the two hemispheres occasionally are interrupted, notably in Batocrinus, Catocrinus and Strocrinus, is readily explained by the large increase that here takes place in the number of arms, which prevents the development of interbrachials around the arm bases.

Essentially different is the ventral structure of the Fistulata, which have no interradial plates in the dorsal cup, the anal plate excepted, but which have these pieces extensively developed in the tegmen. Four of the interambulacral spaces are raised but little above the level of the arm bases, while the posterior area is extended abruptly upward, and is formed into a tube or sac of variable shape and size, rising beyond the tips of the arms. This sac, which may be regarded as a greatly extended anal area, probably lodged a large portion of the visceral mass. The sac is generally composed of longitudinal rows of hexagonal plates, and is often perforated by pores. The structure at the four other sides of the disk is rarely observed except among the Cyathocrinidæ in which it is probably more substantial than in other groups. In Cyathocrinus there are six plates, interradially disposed, resting against the inflected upper edges of the radials, the lateral margins being covered by the ambulacra. Four of them are large and of equal size, the two others, lying at the posterior side, are quite narrow and enclose a madreporite. The margins of the larger plates are roofed over in perfect specimens by numerous small irregular pieces, while the perforated plate is exposed to view.

Most of the Ichthyocrinidæ have interbrachial plates, which in some forms are large and massive, in others small; some are arranged regularly, others irregularly, but all are movable. The plates of the tegmen are very minute and irregularly arranged, the ambulacra are tegminal, and the mouth and food grooves are open. Thus there is among palæozoic crinoids a tegmen having all the characteristics of the disk in recent species, demonstrating conclusively that the disk as a ventral structure is not confined to the neocrinoids as generally supposed. Moreover, a careful study of the various tegmens in the different groups shows that there are represented among them all intermediate stages from the simplest disk to the most rigid and complicated "vault" of the Actinocrinidæ, and that the so-called vault is a highly modified form of the disk.

The anal plates bear a most important part in the phylogeny of palæozoic crinoids, and they are among the best criteria for purposes of classification. When present they occupy, in the Camerata, the median line of the posterior area so as to divide the interbrachial plates into two equal sets, and being in rows containing an odd number they have the effect, as it were, of breaking up the middle plate into two, as in cases where no anal plate is inserted between the sections.

The anal plates vary considerably in their position and distribution, and, in some groups are absent altogether. As a rule they are largely represented in species with a stout tube or a lateral opening, and are wanting or are poorly developed when the anus is central.

Among the Fistulata the term "anal plates" has been applied to two ossicles of different origin, the one radial, the other interradial. The latter is the homologue of the first anal of the Camerata, and rests upon the truncated posterior basal. The other which is not a supplementary plate but the lower section of the compound right posterior radial, performs anal functions only in certain genera. When both plates support the ventral sac as in most of the Poteriocrinidæ, the second, which is actually the first or lowest in point of position, is placed obliquely to the right of the other, without disturbing the orientation or the alternate arrangement with the basals. Both plates undergo many modifications, and the various phases as they occur in different geological stages, may be regarded as excellent criteria for generic separation. The earlier Camerata have neither a radi-anal nor a regular anal plate both of which make their appearance with the increasing size of the ventral sac. As this grows larger, the two posterior radials which previously were in contact laterally, part, and the anal piece is introduced to support the sac. Afterwards when the ventral sac attains still greater proportions, the supraradial is shifted to the right in a position almost directly above the right postero-lateral basal, so as to give to the infraradial which retains its place, a rather oblique direction. In the Poteriocrinidæ, in which the lower faces of the costals fill up the whole width of the radials, leaving no room for attachment, the lower plates of the sac enter the calyx. At the close of the Carboniferous, the sac becomes reduced again to its former insignificance, the anal plates generally disappear, and the two posterior radials meet again laterally. This interpretation of the origin of the anal piece (or plate *x* as it is frequently called) differs essentially from that given by the English writers on the crinoids and particularly by Mr. Bather, who regards the plate as primitively derived from a brachial, which in time passed down from above into the dorsal cup. This author also claims that in the older forms with a compound right-posterior radial, such as in Iocrinus and Heterocrinus, the plate in question is supported by the supraradial and does not touch the infrabasal; but that, further, in Hybocrinus and Dendrocrinus, it passes down from above the radial and finally rests with its lower half between the two posterior radials,

then being supported partly by the basals and partly by the infraradial; and that in Carabocrinus, Botryocrinus, and allied forms the said ossicle has sunk to a line with the radials. Mr. Bather evidently has confounded here plates which are morphologically quite distinct. In the above genera the plate under consideration is represented only by Dendrocrinus, Carabocrinus, and Botrycrinus. The piece to which reference is made in Iocrinus, Heterocrinus and Hybocrinus is a plate of the ventral sac, as is conclusively proven by Dendrocrinus, otherwise it must be admitted that the plate would be represented twice in the same specimen, by the true anal plate which rests upon the basals, and by the tube plate (of Iocrinus) which is supported by the supraradial. The anal area of Dendrocrinus is like that of Poteriocrinus, only that the superradial of the former does not move away from the inferradial, as it does in the latter. This is not necessary in a form like Dendrocrinus in which the arm-facets occupy a comparatively small part of the radials and leave ample space for the support of the tube. In the Poteriocrinidæ, however, in which the upper surface of the radials is taken up completely by the costals, the foundation of the tube is not adequate to the width and the deficiency is manifestly made up by a shifting of the superradial and the introduction of another plate for the support of the tube.

In the anal interradius, as it appears in the various families of the Camerata, a close agreement is found between the anal plate (*x*) and the tube plates of the Fistulata on one side, and the anal plate and interradials on the other. Admitting this, a more satisfactory explanation of the anal plates of the Fistulata is reached than that given by Mr. Bather whose views do not cover the Camerata; besides being based upon premises which appear to be entirely hypothetical. If it were true that Bather's plate *x* of Iocrinus passed down in later forms from above the superradial to the basals, it would certainly require a partial revolution of the whole tube; but this is clearly disproved by the structure itself, which throughout its full length is composed of hexangular pieces, regularly arranged in longitudinal rows. Bather also regards the anals of the Camerata as morphologically distinct from those of the Fistulata, while there actually seems to be good grounds for believing that the plate *x* of the latter is homologous with the first anal in the Camerata, and also with the anal which for a time occurs in the larva of the Comatulæ; but that the Camerata have no radi-anal for the simple reason that they have no compound radials. The anals

of the Icthyocrinidæ are arranged in a similar way to those in the Fistulata. Some of them have only the plate *x* represented, others only the radi-anal, still others both, and some of them have no anal plate at all. The Larviformia have neither the one nor the other, although they have frequently compound radials. The anal tube where it occurs, is inserted intermediate between the radials and orals.

The systematic arrangement of the crinoids as proposed by Wachsmuth and Springer is one that will require but few material changes for a century to come. Based entirely upon morphological principles, with a completeness and wealth of ontogenetic and phylogenetic data that is rarely obtainable among fossil organisms, the essential elements of classification are more firmly grounded than perhaps in any other group. No attempt in recent years towards a natural and rational orderly arrangement of a large and complex assemblage of organic remains has been so signally successful. Nor has the evolution of the groups in time and space been neglected. For classificatory purposes special emphasis should be placed upon a number of features. Of very great importance is the growth of the stem, whether the young joints are formed beneath the proximal ring of the calyx or beneath the top stem joint. Particular stress is also to be placed on the alternate arrangement of the stem with the lower ring of plates in the calyx, by which it is determined that by far the large majority of the neozoic crinoids are dicyclic and not monocyclic. Of exceptional significance are certain features in the Ichthyocrinidæ which clearly indicate affinities with the Apiocrinidæ, Bourgueticrinidæ, Eugeniacrinidæ, and Comatulæ all five groups of which are placed together among the Articulata. All have a disk composed of small, irregular, and movable pieces, with open mouth and open food grooves, all are dicyclic, but the infrabasals coalesce with the top stem joint, so as to prevent the introduction of new joints directly beneath the calyx. From the Articulata are excluded the Encrinidæ and Pentacrinidæ which are generally arranged with them. The infrabasals of the former of the two families are very small, or are resorbed in the growing animal, but they do not coalesce with the top joint which is therefore for the time being the youngest joint of the stem. The Pentacrinidæ have, through the Encrinidæ, close affinities with the Poterocrinidæ, and probably are their descendants, but if they really belong to the Inadunata as is now believed they represent somewhat abberant types, for the lower brachials take part in the calyx.

Not less important than the morphological contributions to a knowledge of the stemmed echinoderms are the advancements made in their classification, and it is safe to say that the systematic arrangement of the group is now practically settled for a century to come.

The three groups of stalked echinoderms, the cystids, blastoids and crinoids are regarded as orders of equal rank. The forms of the first are earliest in time and lowest in taxonomic position, and may be considered the ancestral types of the other two. The crinoid type itself is a very old one, dating from the Cambrian, in which it was already in a high stage of development. During the Ordovician the cystidian features almost wholly disappeared. The crinoidal group is remarkable for the persistency it has shown in preserving its pentamerous symmetry, and although the introduction of the anal plate was a disturbing element so great as to well-nigh produce a lasting bilateral arrangement, the former type was finally permanently retained.

The two primary groups of crinoids which were formerly almost universally accepted are abandoned. These are the Neocrinoidea and Palæocrinoidea. In their stead are recognized three principal subdivisions: Inadunata, Camerata and Articulata. It is particularly noteworthy that this ternate grouping of the crinoids is essentially the same as Wacksmuth originally proposed more than twenty years ago and that after being compelled by students of the recent forms to abandon it and to substitute others, a final careful survey, in the light of recent discoveries, of all crinoids both living and fossil, has clearly shown that the main subdivisions first suggested are essentially valid and are applicable to all known forms. The criteria for separating the crinoids into orders are briefly:

1. Condition of arms, whether free above the radials, or partly incorporated in the calyx.

2. Mode of union between plates of the calyx, whether movable or rigid.

3. Growth of the stem, whether new plates are formed beneath the proximal ring of the calyx or beneath the top stem joint.

The simplest forms of the Crinoidea Inadunata have the dorsal cup composed invariably of only two circlets of plates or three where infrabasals are present; there are no supplementary ossicles except an anal piece which is however not always present; the arms are free from the radials up. In the construction of the ventral disk two different plans are recognizable and upon these are established two subgroups—

the Larviformia and Fistulata. The former has the disk in its simplest possible form, being made up of five large orals arranged in a pyramid; the second has the ventral side extended into a sac or closed tube, often reaching beyond the ends of the arms.

The Camerata are distinguished by the large number of supplementary pieces which bring the proximal arm plates into the calyx, thus enlarging the visceral cavity. All plates are heavy and immovable and the mouth and food grooves are tightly closed.

The Articulata have to some extent the incorporation of the lower arm plates with the calyx, but the plates are movable instead of rigid. The mouth and food grooves are open. The infrabasals are fused with the top stem joint which is not the youngest plate of the stalk. According to whether or not the pinnules are present two suborders are recognized: the Pinnata and Impinnata.

For the family distinctions the supplementary plates constitute excellent features for classification, and while of small importance physiologically, they form a good example of a truth which is met with everywhere in biology that characters of physiological value are not always of equally great utility for purposes of classification. Of prime import in this regard are the anal pieces.

Of the three groups of crinoids having ordinal rank, that constituting the Camerata is by far the most important. An analysis of the families is briefly as follows:

I. Lower Brachials and Interbrachials Forming an Important Part of the Dorsal Cup.

A. Interradials poorly defined.

Lower plates of rays more or less completely separated from those of other rays and from primary interradials by irregular supplementary pieces; anal interradius divided by a row of conspicuous plates; (dicyclic or monocyclic) ..... Reteocrinidæ

B. Interradials well defined.

1. Dicyclic.

a. Radials in contact, except at the posterior side ..... Thysanocrinidæ

b. Radials separated all around ..... Rhodocrinidæ

2. Monocyclic.

a. Radials in contact all around. Symmetry of the dorsal cup if not strictly pentamerous, disturbed by the introduction of anals between the brachials only ..... Melocrinidæ

Arms borne in compartments formed by partitions attached to tegmen; dorsal cup perfectly pentamerous; plates of calyx limited to a definite number ..... Calyptocrinidæ

b. Radials separated at the posterior side by an anal plate.
First anal plate heptagonal, followed by a second between interbrachials. ..... BATOCRINIDÆ
First anal plate hexagonal, followed by two interbrachials without a second anal; arms branching from two main trunks by alternate bifurcation ..... ACTINOCRINIDÆ

II. BRACHIALS AND INTERBRACHIALS ONLY SLIGHTLY REPRESENTED IN THE DORSAL CUP.

1. Dicyclic.
Radials in contact except at the posterior side ..... CROTAOCRINIDÆ
2. Monocyclic.
a. Radials in contact all around; base pentagonal ..... PLATYCRINIDÆ
b. Radials separated on posterior side by an anal plate; base hexagonal. Basals directly followed by the radials ..... HEXACRINIDÆ
Basals separated from radials by accessory pieces ..... ACROCRINIDÆ

While the morphological and classificatory chapters of the monograph on North American crinoids appeal more directly to palæontologists interested in the biological side of the subject, the descriptive part will be of greatest practical value to the stratigraphical geologist. This portion of the work is a complete revision of all Camerata known from this country up to September 1894. Every species is fully and clearly described compared with closely related forms, beautifully illustrated and referred to its proper geological horizon; the full literature of each and the localities where it occurs are also given. All the species have been redescribed from the most perfect material that could be found in all museums and private collections. The liberality shown Wachsmuth and Springer by those persons who possessed suitable specimens in placing them at free disposal is to be commended in the highest terms. It was the means of making accessible nearly all the type specimens known, and in fact, most of the crinoid material in the country. In addition there were the authors' own magnificent collections which contain more than nine-tenths of the known American species and over two-thirds of the European, of which many are represented by scores and even hundreds of individuals. These large collections gave new ideas regarding the limits of the different species and enabled a discrimination to be made between species and varieties, and between the young specimens and the adults, which led to the elimination of a large number previously recognized. The establishment of species on rational morphological grounds and not on trivial superficial or accidental characters which are relatively unimportant as classificatory criteria is a point of excellence which cannot be too highly praised, and one which should

be the central consideration in the revision of the nomenclature of all groups of fossils as well as living organisms. That there has long existed a burdensome and extensive synonomy among crinoidal as well as all other classes of animals no one who has given the subject attention will for a moment question. The most casual consideration has rendered apparent the urgent necessity of a careful and complete revision of nearly all groups. The wide geographical distribution of many species and the concomitant changes of environment may readily be referred to as among the chief causes of local variation in species now living. Among fossil forms, however, there is in addition a greater factor of geological range which must be carefully considered. Notwithstanding the careful and conscientious labors of a large number of writers, little attention has been given in the description of species to these highly important factors which for the most part have been entirely overlooked. But the contributions to synonymy have not originated wholly in the manner mentioned. A still greater number of invalid names have come from a practice which cannot be condemned in terms too severe. It is the tendency to describe species, and genera also, from imperfectly preserved material, often from a single aberrant specimen, without making adequate comparisons with allied forms. This deplorable state of things, which in the natural course of events should be continually getting better with the advance of knowledge, appears of late years to have become so virulent that it is a serious question whether such work should not properly be ignored altogether. It will ever remain one of the crowning glories of Wachsmuth and Springer's efforts that they have shown no sympathy whatever with such work; and that with calm, untrammeled and truly scientific judgment they have relegated to oblivion such a large number of worse than useless specific names which have so long stood as a menace to progress in this field of palæontologic research. A full list of synonyms so far as they apply to the Camerata is given.

The preparation of the monograph occupied over seven years of continuous work, but this gives but a faint idea of the vast amount of labor involved. This work will be indispensable to all future writers on crinoids, as well as to the collector in the identification of his material. It embraces the whole literature on the subject and thus dispenses with dozens of papers which are not accessible to the student. Besides it has the great advantage that the same terms are used throughout the whole work, and that these terms are clearly and accurately

defined. The identification of the forms is facilitated by analytic tables for families and genera; and the species are arranged under the various genera in such a way that those most closely related are placed near one another. There is a general index, and an index of the authors quoted. CHARLES R. KEYES.

En resa till norra ishafvet sommaren 1892, företagen med understöd af vegastipendiet. [A Journey to the Arctic Ocean during the Summer 1892, made with the aid of the Vega Stipend.] By AXEL HAMBERG. Reprint from Ymer, 1894.

The author accompanied a Norwegian sealer visiting Beeren Island and the Spitzbergen Islands. In King's Bay a stay of several days was made, and the author studied some ice fields, which he named Lovèns névés. On the surface of the ice at this place but few small lateral moraines were to be seen, but in a fracture of the ice an inner moraine was observed. This consisted of about ten strata of assorted gravel and sand alternating with layers of ice. It was evidently a medial moraine in the lee of a projecting low mountain top, seen several miles inland. It is stated that similar features are common in the ice fields of these arctic islands. The author suggests that, if the ice were melted away, such moraines would give rise to structures much resembling åsar, both as to the contained material and as to the form and direction of the resulting topography. At one place some of these deposits were seen extending a distance at right angles away from the ice margin and resembling somewhat the Scottish kames. The névés were composed of bedded ice, in some places extending out in the sea. In several instances it had been melted away under the water and marginal blocks had evidently been detached by their own weight, leaving the edge of the ice standing in vertical smooth walls as if "cut off with a knife."

A number of photographs were taken with a camera fitted for photogrammetric measurements and a map constructed from these photographs accompanies the paper. The névés represented on this map are seen to occupy valleys among several small groups of hills and extending to within less than a mile from the shore. The front edge of the ice sometimes forms an evenly rounded curve and sometimes a vertical cliff from 60 to 100 feet high. It is suggested that this difference in the behavior of the terminal edge (when resting on the land) may be due to a difference in the morainic material of the

ice. The vertical escarpments could not here have been formed by the breaking-off of any blocks, for no such were in view. They may have been made, or they may at least be maintained in their present attitude by the difference in the motion of the upper and lower layers of the ice, the lower strata being held back by friction with the ground, and the higher pushing out over them. It is intimated that such behavior of the superimposed layers was observed.

The stratification of the ice was everywhere marked. Sometimes the layers were folded. In one of the illustrations of the paper an S-shaped bending of the strata occurs where the ice is forced up over the moraine in front. In another place cracks are shown running at right angles with the lamination of the ice. Sometimes there were veins (of clear ice?) branching and extending in various directions. One of these veins was over a meter in thickness. These veins seemed to have been formed by running water and are an indication of the internal conditions of temperature.

The morainic material of the ice consists of intercalated thin layers above. Next to the ground these layers are sometimes three feet in thickness. A lenticular mass is shown in one illustration, where the weight of the inclosed material has flexed the layers below in an even curve. With the exception of the lowest layers of the moraine its material is believed to have come from the nunataks, which rise through the ice. These are subject to intense weathering from frost, the detached material sliding down on the ice and becoming imbedded in it, as it forms from the falling snow. No striated bowlders were observed, but there was a great deal of rounded as well as of angular material. The surface of the rounded bowlders was seen to be covered by a fine powder. Even the bowlders in the upper layers of the ice are well rounded. The author's observations support the view that the intercalated layers of morainic material are planes of shearing, where the material is rolled between two layers of ice of relatively different rate of horizontal progression. The shearing within each stratum of ice is probably quite insignificant. It is regarded as likely that the mode of motion in a névé of stratified ice is in this respect essentially different from that in homogeneous glacier ice.

With a few exceptions the névés seen near King's Bay appear to be advancing. In one instance the edge of the ice was seen rising on the rear slope of a moraine in front. This is referred to as a proof that a névé may be caused to have an ascending current by a horizontal

thrust from behind. The glacial features seen in King's Bay are particularly interesting for the close resemblance they bear to those observed by Professor Chamberlin in Greenland. J. A. UDDEN.

Palæontographia Italica. Memorie di paleontologia. Pubblicate per cura del PROFESSOR MARIO CANAVARI. Vol. I., 1895, Pisa, 1896.

This is a new palæontological publication modeled on the *Palæontographica* of Germany, whose purpose is to unite in a central organ for leading memoirs on the fossils of Italy. The first number is an ample and interesting volume of 275 pages and eighteen lithograph plates.

The first paper is by C. F. Parona on "Nuove osservazioni sopra la fauna e l'età degli strati con *Posidonomya alpina* nei Lette Comuni," pp. 1–42, Plates I. and II.; it is a continuation of Parona's monograph "I fossili degli strati a *Pos. alpina* di Camporovere nei Lette Comuni" Atti della Soc. di Lei. Nat. Milano, Vol. XXIII., 1880. In the present paper the author has described and listed a large fauna of the Middle or Brown Jura, most of the species being new, only a few of the familiar names of Quenstedt's, Oppel's, and Sowerby's species appearing among them.

The paper by A. Tommasi, "La Fauna del Trias inferiore nel versante meridionale delle Alpi," pp. 43–76, Plates III. and IV., describes fifty-three species, of which eight are new. The entire fauna consists of one brachiopod, thirty-four pelecypods, eleven gasterpods, and seven cephalopods, all ammonites but one.

The third paper of the volume is by Antonio Neviani, "Briozoi fossili della Farnesina e Monte Mario presso Roma, pp. 77–140, Plates V. and VI. The author describes one hundred and ten species and varieties of Tertiary Bryozoa, of which about three-fourths are still living in the Mediterranean and adjacent seas. Useful and interesting notes on distribution in space and depth are also given.

The fourth paper is by C. Fornasini, on "Foraminiferi della marna del Vaticano," p. 141–148, Plate VII. In this short space twenty-three species are described and listed, although none are new.

The fifth paper is by V. Simonelli, "Gli antozoi pliocenici del Ponticello di Savena presso Bologna," pp. 149–168, Plate VIII. Twenty-three species of Pliocene corals are described, many of which are still living in the Mediterranean and Atlantic waters.

The next paper is that of Francesco Bassani, "La Ittiofauna della Dolomia principale di Giffoni (Prov. Salerno)," pp. 169–210, Plates

IX.–XV. From the Trias, Bassani describes eleven species, representing eight genera, and five families.

The most important memoir of the volume is that of Vinassa de Regny, "Synopsis dei molluschi terziari delle Alpi venete, Parte prima: Strati con Velates Schmiedeliana," pp. 210–275, Plates XVI., XVIII. Heretofore papers on Italian Tertiary geology have been badly scattered and hard to get at, but de Regny's memoir will help to remove this difficulty by republishing in accessible form many obscure figures and descriptions.

All the papers in Volume I. of the *Palæontographia Italica* are well indexed, and have copious bibliographic lists appended, an example that other palæontological publications might well follow. J. P. S.

The Soil; its Nature, Relations, and Fundamental Principles of Management. Pp. xv.+303, illustrated. By F. H. KING. New York, 1895.

This little book was written for students of agriculture, but it contains so much of interest to students of geology that we give it room here.

The distinctly geological matter in the volume is well chosen, and the geological illustrations are all helpful and to the point. The following topics are of especial interest to geologists: origin of soils, methods of rock disintegration, sediments moved by streams, work of rain, composition of soils, nitrogen of the soil, capillarity, solution and osmosis, soil water, distribution of roots in the soil, relations of air to soil.

One of the commendable virtues of the book is the simplicity of the writer's style: complex problems of chemistry, physics, geology, and botany are all dealt with in the simplest manner possible. There is no laborious argumentation to bewilder the new student. The occasional dropping into poetry will strike the critical as rather overdoing the matter perhaps, but there is nothing to detract from the dignity of the subject under consideration.

It is to be hoped that the author of this valuable little book will soon give the world the benefit of his more technical knowledge of the physics and chemistry of soils expressed in his clear, easy style, and accompanied with the references needed by advance students and investigators.

Aside from the value such a work may have for agriculture, it will aid geologists to understand the work of water and acids in the alteration of minerals and rocks, the agencies of rock decomposition and the formation and modification of many ore deposits. J. C. B.

AUTHORS' ABSTRACTS.

The Loess of Western Illinois and Southeastern Iowa. By FRANK LEVERETT, Denmark, Iowa.

The north border of the loess both in western Illinois and eastern Iowa appears to have been determined by the ice-sheet. The loess is apparently an apron of silt spread out to the south by water issuing from the ice-sheet. It is loose textured at the north and becomes finer textured toward the south, showing a decrease in the strength of depositing currents. The wide extent of the loess over the uplands has led to a consideration of the influence of the wind as well as water in its distribution. It is thought that wind-deposited loess may be distinguished from that which is water-deposited. The wide extent, however, appears to be due to water-distribution rather than wind. Wind action apparently came into force subsequent to the water distribution and is of minor importance.

Possible Depth of Mining and Boring. ALFRED C. LANE. Geol. Society of America, Philadelphia, 1895.

The paper was prepared for the forthcoming volume of *Mineral Industry*. The possible depth of mining was studied from the construction of a curve representing the minimum cost of mining at various depths. The chief factors in increasing the cost were found to be the increased length of time required for a hoist, and the increasing temperature. Stress was laid on the efficiency of the escape of compressed air in neutralizing the increasing rock temperature, and the rate of increase in temperature in the Lake Superior copper mines was discussed, with the result that an increase in temperature of not more than 1° F. in 100 feet could safely be assumed and that in all probability a depth of 10,000 feet could be reached without insuperable difficulty. A shaft is now down 4800 feet, and another one started which will not reach the lode until it is down 5000 feet. In the discussion following Professor Shaler suggested that the low temperature gradient might be due to the cooling effect of the use of compressed air in the mines, and Mr. Lane suggested that it might also be due to a

rise in the surface temperature since glacial times, and suggested that the Wheeling record indicated that, or it might also be due to the cooling effect of downward percolating waters. He urged the advantage of an exploratory boring from the bottom of one of these shafts which might thus penetrate nearly 15,000 feet into the earth's crust.

The Soils of Texas. By E. T. DUMBLE. Texas Academy of Science, 1895, pp. 60 and 1 map.

A preliminary classification of Texas soils is offered based upon their geological relations and origin. It is preceded by a brief statement of the general geology and of the main topographic features of the state. This is followed by a general description of the characteristic residual soils of the principal horizons of the various geological formations present. A brief statement is then made as to the characters of the drift soils and a somewhat more extended description of the great body of fertile alluvial soils is given, especial attention being called to those of the Brazos and Rio Grande.

The Yardley Fault. By BENJAMIN SMITH LYMAN. Proc. Am. Phil. Society, Vol. XXXIV., 1895.

A conspicuous normal fault in the railroad cut near Yardley, Bucks county, Pa., had seeming importance from a mistake, through certain optical illusions, in the direction of its dip and downthrow; but a correct geometrical construction shows the displacement to be no more than perhaps twelve feet. The blackish, highly quartzose filling is derived from neighboring gneiss, or still closer sand rock, and not from trap, as once imagined. Small geological and topographical maps of the neighborhood and of the fault, with a cross-section, are given.

The Chalfont Fault Rock, So-called. By BENJAMIN SMITH LYMAN. Proc. Am. Phil. Society, Vol. XXXIV., 1895.

The so-called fault rock of the Chalfont railroad cut, Bucks county, Pa., formerly supposed to fill confusedly a fault 100 feet wide that heaved a nearly vertical trap dike about five miles, is merely much cleaved, somewhat folded, dark shale-beds, dipping seventy degrees, or less, and striking acutely across the railroad. Two photographic views along the strike are given in demonstration.

Crystalline Limestones and Associated Rocks of the Northwestern Adirondack Region. By C. H. SMYTH, JR.

Extensive belts of highly crystalline limestone constitute an important feature of the region. These belts are separated by wide areas of rather massive gneisses, whose origin and relations to the limestone are obscure, and afford the chief problem for future investigation. They are probably largely igneous.

Rocks whose igneous origin has been clearly ascertained are scattered over the whole area. They are chiefly granite, diorite, gabbro and diabase. These are all younger than the limestone, cutting it with typical irruptive contacts, often affording a variety of contact minerals.

The most extensive igneous rock passes into a gneiss which spreads over a wide area and is quite similar to many of the other gneisses. This gives a clue to the origin of the latter. Some of the granites are suggestive in the same direction.

Much crumpling and crushing in the limestone series is indicative of dynamic metamorphism, but should most of the gneisses prove to be intrusive it would strengthen the hypothesis of thermal metamorphism on a large scale.

U. S. Geologic Atlas, Folio 1, Livingston, Montana, 1894.

This folio consists of three and one-fourth pages of text, a topographic sheet (scale 1:250,000), a sheet of areal geology, one of economic geology, one of structure sections, and one giving a columnar section. The text is signed by Joseph P. Iddings and Walter H. Weed, geologists, and Arnold Hague, geologist in charge.

The area of country covered by the folio lies between the parallels of latitude 45° and 46° and the meridians 110° and 111°, and embraces 3340 square miles. It is within the state of Montana, including portions of Gallatin and Park counties, and the town of Livingston is within its limits. The region is elevated, the lowest point being over 4000 feet, the major portion over 6000 feet, and the highest peaks over 11,000 feet, above sea level.

The principal topographic features are the Snowy Mountains, Gallatin Range, Bridger Range, Crazy Mountains, and Yellowstone Valley. The Yellowstone River is the main drainage channel for the area. It enters the district from the Yellowstone Park about the middle of the southern border, flows northwest and north through a closed valley thirty miles long and three miles wide, and at Livingston

turns northeast and enters the broad, open valley beyond the frontal ranges of the Rocky Mountains.

The rocks forming the surface of the country are partly crystalline schists, including gneiss schist, with granite and other granular rocks; partly sedimentary formations, including limestone, sandstone, and shales; and partly lavas and other igneous rocks. The crystalline schists are mainly Archean, and constitute a large part of the southern half of the region. They form the high mountains and plateau drained by Boulder River, and those from Emigrant Peak south. A small area of sandstones, conglomerates, slates, and arenaceous limestones occurring in the Bridger Range have been referred to the Algonkian. They lie unconformably upon the crystalline schists, and are overlain unconformably by the Palæozoic series.

The sedimentary formations cover one-half the area, and present a total thickness of 20,000 feet, embracing all the grand divisions of geologic time since the Archean. The chief feature is the great development of the latest Cretaceous strata, which are 12,000 feet thick above the Laramie, the total thickness of the Palæozoic being only 3500 feet. The series from the basal (Flathead) quartzite to and including the Laramie coal beds, is conformable throughout. The Palœozoic strata occur upturned at steep angles against the crystalline schists, or in steep anticlines. The lowest bed is the Flathead quartzite. Above it are shales and limestones of Cambrian age. The Silurian is represented by only a few feet of formation, whose precise age is doubtful. Four hundred and fifty feet of shales and limestones represent the Devonian. The Carboniferous strata are 2000 feet thick. They are here, as elsewhere, the mountain limestones, and form the crest of the Bridger Range and the summits of some peaks of the Snowy Range. The Trias is recognized only in the southern part of the region, as thin belts of red sandstone. The Jura varies considerably in character, being mostly shales and fissile limestones. These two formations are 500 feet thick.

The Cretaceous constitutes more than one-half of the total thickness of strata. Its lowest member is the Dakota conglomerate, with sandstone and some shale. Over this is the Colorado group, including Benton shales and Niobrara limestone, aggregating 1800 feet in thickness. Over this is the Montana group, 1800 feet thick, consisting of Pierre shales and Fox Hills limestone. The Laramie sandstone, with some intercalated clays and beds of coal, is 1000 feet thick. Above

this is a slight unconformity, followed by conglomerates, sandstones, and clays of the Livingston formation, 12,000 feet thick. Near the base the conglomerate consists largely of volcanic material. True tuff-breccia of volcanic rocks occurs intercalated near the base of the series on Boulder River.

Neocene lake beds occur in Gallatin Valley, and on Yellowstone River, opposite Fridley.

Superficial deposits of the Pleistocene period occur as alluvium over all the broader river valleys. Glacial drift, consisting of gravel, sand, and bowlders, is scattered over the higher parts of the country, and covers the Yellowstone Valley south of Chicory.

Igneous rocks occupy a large part of the area of this sheet. They consist of subaërial breccias or agglomerates, with tuffs and lava-flows, and of intrusive bodies, such as dikes, sheets, laccolites, and stocks or necks. They occur extensively in the southeastern corner of the district, and form the Gallatin Range along the southwestern border, and another area east of Boulder River. In the Crazy Mountains the igneous rocks are wholly intrusive. The extrusive rocks are andesitic breccia, acid and basic; trachytic rhyolite, rhyolite, and basalt. The intrusive rocks are gabbro, diorite, theralite, basic and acid porphyries, basic and acid andesites and dacites. Several centers of volcanic eruption, active in early Tertiary time, occur in the region. They are at Emigrant Gulch, Haystack Mountain, and Crazy Mountains. Other centers are just outside of the limits of the atlas sheet.

The chief economic deposits of the district are the gold-bearing gravels of Emigrant, Bear, and Crevice gulches. They have been worked on a small scale. Gold veins occur in Emigrant Gulch, Crevice Gulch, and Haystack Mountain. Copper ores in small quantities have been found at the head of Boulder River and of Slough Creek. Clays serviceable for brick-building occur in the alluvium near Livingston, and in the lake-beds near Bozeman, also in the Cretaceous strata. Two coal fields exist within the district, the Cinnabar field and the Bozeman field. The aggregate thickness of the coal is twelve to eighteen feet, made up of a number of seams, only three of which are workable. The coal is bituminous, of variable character, and in places is a fair coking coal. The output in 1889 was 49,400 tons.

U. S. Geologic Atlas, Folio 3, Placerville, California, 1894.

This folio consists of one and one-half pages of text descriptive of the Gold Belt and one and one-half pages descriptive of the

Placerville district, signed by Waldemar Lindgren and H. W. Turner, geologists, and G. F. Becker, geologist in charge; a topographic map (scale 1:125,000) of the district, a sheet showing the areal geology, another showing the economic geology, and a third exhibiting structure sections.

Geography.—The territory represented lies between the meridians 120° 30′ and 121° and the parallels 38° 30′ and 39°, and contains 925 square miles. It is located in the upper foothill region of the Sierra Nevada, the elevation ranging from 300 feet to 5400. The prevailing character of the topography is that of irregular and undulating plateaus cut by deep canyons and steep ravines. The district is drained by the three forks of the American River in the northern part and by the three forks of the Cosumnes River in the southern part.

Geology.—The eastern half of the tract is principally composed of a somewhat metamorphosed sedimentary series, the Calaveras formation, of presumable Carboniferous age. The rocks consist chiefly of clay-slates and quartzitic sandstones, and have in general a northerly strike and steep easterly dip. Several irregular intrusive masses of granitic rocks are contained in the sedimentary series. The western half of the tract is much more complicated. A belt of black slates belonging to the Mariposa formation, or late Jurassic age, traverses the tract from north to south. To the west of this belt follow again sedimentary rocks of the Calaveras formation, greatly cut up by igneous rocks. The sedimentary rocks here, as well as in the western part, have a northerly strike and steep easterly dip. The western part of the area contains a great abundance of basic igneous rocks, consisting of diabase, augite, hornblendic porphyrite, gabbro-diorite, pyroxenite, and serpentine. Over large areas certain of these basic rocks have been converted to amphibolitic schists by dynamo-metamorphic processes. Covering the ridges and resting unconformably on the older rocks are large masses of Neocene effusive rocks, chiefly tuffs and breccias of rhyolite and andesite. These masses form gently sloping tables, underneath which the Neocene gravel channels are found.

Economic geology.—The Neocene river channels, with very highly auriferous gravel, are exposed and mined at several places in the area, for instance, at Todd's Valley, near Georgetown, and in the vicinity of Placerville. Many and important auriferous quartz veins are found in

the area. The principal ones occur along the belt of Mariposa slates previously mentioned, and form the northern end of what is usually referred to as the Mother Lode of California. Passing by Nashville and Placerville, the vein is almost continuous up to the northern part of the area, where it splits up into several branches, which die out before reaching the northern border. Important veins are, however, also found both to the east and west of this belt. Near the eastern line lies the important mining district of Grizzly Flat.

There are practically no alluvial soils in the area. The deep soil on the summit of the ridges is always a residual soil, formed by the decomposition of the rocks in place.

U. S. Geologic Atlas, Folio 5, Sacramento, California, 1849.

This folio consists of one and one-half pages of text descriptive of the Gold Belt and one and one-half pages descriptive of the Sacramento tract, signed by Waldemar Lindgren, geologist, and G. F. Becker, geologist in charge; a topographic map (scale 1 : 125,000) of the tract, a sheet showing the areal geology, another showing the economic geology, and a third exhibiting structure sections.

Topography.—The Sacramento tract includes the territory between the meridians 121° and 121° 30′ and the parallels 38° 30′ and 39°, and contains 925 square miles. The western half of the tract embraces a part of the Sacramento Valley, while the eastern half contains the first foothills of the Sierra Nevada. The elevation ranges from 30 feet above sea level at Sacramento to 2100 feet in the northeastern corner of the tract. The foothill region forms a sloping and undulating table-land, through which the American River has cut a deep and narrow canyon.

Geology.—A small area of sedimentary slates of the Calaveras formation (Carboniferous) occurs in the northeastern corner, and a belt of black clay-slates belonging to the Mariposa formation (late Jurassic) is contained in the igneous rocks of the southeastern part. At Folsom the Mariposa slates are cut off and contact metamorphosed by the granitic rocks of the Rocklin massif. The larger part of the older rocks of this tract is of igneous origin. A large area of diabase and porphyrite is found along the eastern margin. Wide belts of these rocks have been rendered schistose and changed to amphibolites by dynamo-metamorphic processes. Several masses of granodiorite and gabbrodiorite have been intruded into the diabases, porphyrites, and

amphibolites. Small masses of serpentine are sometimes found in the amphibolite; others appear intimately connected with gabbrodiorite.

Superficial flows of andesitic tuffs and breccias cover the older rocks. The larger part of these flows has been eroded. The remaining masses form sloping tables in the lower foothill region. Auriferous gravel channels are found in places below these volcanic rocks. At an elevation of 300 feet the andesite is underlain by clays and sands of the Ione formation, deposited in the gulf which in Neocene times skirted the foothills of the Sierra Nevada. The western part of the tract is largely covered by early Pleistocene deposits of gravel, sand, and hardpan.

Economic geology. Neocene auriferous gravels have been worked to some extent east of Rocklin and south of Auburn. The Pleistocene gravels in the foothills have been very rich in gold, but are now mostly exhausted. At Folsom large masses of Pleistocene gravels are still worked. Auriferous quartz veins have been extensively worked between Ophir and Auburn. Small veins are occasionally worked near Clarksville and in the vicinity of Pilot Hill.

The central mass of granodiorite affords excellent building stone. Limestones occur chiefly as lenses in amphibolite at many places along the eastern border. The soils of the foothill region are residuary in character, while the western part of the tract is occupied by deep alluvial and sedimentary soils.

U. S. Geologic Atlas. Folio 7, Pikes Peak, Montana, 1894.

THIS folio consists of four and-a-half pages of text, signed by Whitman Cross, geologist, a topographical sheet (scale 1:125,000), a sheet of areal geology, one of economic geology, and one of structure sections; followed by a special description of the Cripple Creek mining district, consisting of one page of text on the mining geology, by R. A. F. Penrose, Jr., and a map (scale 1:25,000) showing the economic geology of the district.

Geography.—The district embraces an area of 931.5 square miles, between meridians 105° and 105° 30′ and parallels 38° 30′ and 39°. In its eastern half lies the crest of the granitic Colorado Range, which extends from Manitou Park though Pikes Peak to the southern end of the range, where it sinks to the level of the plains. The western portion of the area is a plateau of granite and volcanic rocks, lying between 8000 and 10,000 feet in elevation, penetrated on the south by deep

canyons of streams tributary to the Arkansas River and by the recess or bay of Garden Park, nearly at the level of the plains. The principal drainage of district is by tributaries of the Arkansas River, which flows through the Royal Gorge just beyond the southern boundary. The remaining drainage is into the Platte River, which cuts across the northwestern corner of the area in a deep canyon.

The Colorado Midland Railroad traverses the district from east to west near its northern boundary. East of the center of the area is the mining district of Cripple Creek, reached by branch railroads from the north and south.

General geology.—The granites of the mountains and plateau regions are reddish in color, coarse or fine grained, and similar to those of many other regions in Colorado. Of special interest is the observation, first made by the survey corps, that these granites contain many large and small fragments of metamorphosed stratified rocks, quartzites and schists, belonging to the oldest series of sedimentary beds, the Algonkian; and hence the granites are not of Archean age, as has previously been assumed. Most, if not all, of the gneisses in this district have been formed from the granites by a shearing strain, as is very clearly demonstrated in many places.

The sedimentary formations of the area, and their characteristics of special interest, may be concisely referred to as follows:

Algonkian.—Nearly 4000 feet of white quartzite, in small part conglomeritic, is shown in the huge inclusion in granite in Wilson Park. These ancient strata are not known in this region except as inclusions.

Silurian.—Three divisions of the Silurian strata, each about 100 feet thick, have been recognized in Garden Park, and named respectively the Manitou limestone, Harding sandstone, and Fremont limestone. The Harding sandstone contains the oldest fossil fishes as yet known. Minor uncomformities separate these formations, and they are not known in so good development elsewhere.

Carboniferous.—Resting on the Silurian is a thin limestone, called the Millsap, carrying a few Carboniferous shells, and known only in small remnants. The red sandstones and grits of Manitou and Garden Parks, 1000 feet in thickness, are considered as of Carboniferous age, and named the Fountain formation. No fossils are known in them.

The strata of the Juratrias and Cretaceous have been found in remnants upon the granite plateau, indicating a former extension of these beds connecting with South Park.

Eocene—The small lake deposit about Florissant is noted the world over for its fossil insects, while fishes, birds, and many plants are also found in these thin beds, which are chiefly made up of volcanic ashes.

The volcanic rocks of the district are numerous and interesting. Those of the western portion belong to a great volcanic center south of South Park. At Cripple Creek is a local volcanic vent the peculiar product of which is the rare rock phonolite.

Many points in the geological history of the Colorado Range have been brought out by the recent survey, such as the evidence of varying relations between land and sea at different periods, shown by unconformities and by remnants of strata on the granite plateau. The shear zones shown by the gneisses, and the observed folds and faults of the foothills, bear directly upon the structural history of this portion of the Rocky Mountains.

Economic geology.—The gold-bearing district of Cripple Creek is directly connected with the volcanic center. The gold ores are free milling near the surface, but pass into telluride smelting ores in depth. They occur in veins, chiefly in the volcanic rocks, but occasionally in the granite near them. The extreme alteration of the rocks of the eruptive center, and the unusual character of the gold veins, have made a detailed study of the mining district necessary. A special topographic and geologic map on the scale $\frac{1}{2500}$, or nearly 2½ inches to the mile, has been made, and the ore deposits have been thoroughly examined by Professor R. A. F. Penrose, Jr.

U. S. Geologic Atlas. Folio 9, Anthracite—Crested Butte, Colorado, 1894.

This double folio consists of three pages of text descriptive of the Elk Mountains, by S. F. Emmons; two pages descriptive of the igneous formations of the two districts, by Whitman Cross; four pages descriptive of the sedimentary formations, by G. H. Eldridge; of each of the two districts a topographic map (scale 1:62500), a map of areal geology, another of economic geology, and a third of structure sections; and finally, a sheet showing a generalized columnar section of the two districts.

Geography.—The combined area represented on the two sheets covers one-eighth of a degree, lying between the parallels 38° 45′ and 39′ and the meridians 106° 45′ and 107° 15′, and is about 27½ miles long from east to west and 17½ from north to south. It includes the southern third of the Elk Mountain group, which lies between the

Sawatch Range on the east and the plateau of the Colorado basin on the west. It is a highly picturesque and mountainous region, and, like the San Juan Mountains to the south, has a more abundant precipitation and is more Alpine in its character than other parts of the Rocky Mountains.

The northern half of the eastern or Crested Butte tract is occupied by the southern portion of the Elk Mountains proper, whose culminating points have an elevation of over 13,000 feet; the southeastern portion of that tract includes the distinct and less elevated Cement Mountain uplift. The rest of this area and the whole of the Anthracite tract is occupied by more or less isolated mountain peaks — Crested Butte, Gothic Mountain, Mount Wheatstone, etc. — and by one prominent north-and-south ridge, the Ruby Range, whose higher summits rise between 12,000 and 13,000 feet above sea level.

The drainage of all this area finds its way through the Gunnison River into the Colorado, and the greater part is carried to the latter stream through the southward-flowing Slate River and its tributaries.

The towns of Crested Butte (9000 feet) and Baldwin (8750 feet), which are near active coal mines, are reached by branches of the Denver and Rio Grande and the Denver and South Park railroads respectively. Other towns higher in the mountains, which were founded by silver miners, are Gothic, Pittsburg, and Irwin. Owing to its great altitude and abundant precipitation, this region is more or less snowbound during eight months of the year, and mining is thereby rendered difficult and costly.

Geological structure.— The most striking feature in the geology of the region is the great development of eruptive rocks which occur as irregular bodies cutting across disturbed and upturned strata; as laccolitic bodies doming up the nearly horizontal strata above a given horizon; as vertical and comparatively narrow dikes; to a limited extent as surface flows; and as a bedded series of breccias, tuffs and conglomerates.

Eruptive activity was most energetic and widespread during the Eocene Tertiary; it continued, however, sporadically, during later periods, the most recent outpourings of lava being probably of Pleistocene age. The principal rock types represented are: in the irregular cross-cutting masses, granite and diorite, and at a later period and in limited areas, rhyolite; the laccolites are mostly of porphyrite, among dike rocks are found diorite, porphyritic diorite, porphyrite, and quartz

porphyry; basalt occurs as a surface flow, and andesitic débris in the tuffs and conglomerates of the bedded series.

Among sedimentary rocks in this region are found representatives of the principal formations from the Archean up to the close of the Mesozoic, with some later formations whose exact age is still somewhat doubtful.

The Cambrian is represented by the Sawatch quartzite, which consists of 50 to 200 feet of white quartzite, conglomeritic at the base, and at certain horizons persistently glauconitic; its fossils are of the Potsdam type.

The Silurian beds, which are locally called the Yule limestone, in an aggregate thickness of 350 to 450 feet consist mainly of limestones, with quartzite at the base and more shaly beds at the top. They contain the same fish remains that characterize the Harding sandstone of the Canyon City section, but organic remains have not been discovered in sufficient abundance to admit of the subdivison of the series on a palæontological basis.

The Carboniferous is represented by three subdivisions. (1) The Leadville limestone, or Lower Carboniferous, has a thickness of 400–525 feet of dark-gray or blue limestones, with some intercalated quartzites and shales. Above this is (2) the Weber formation, which consists of 100–500 feet of shales and limestones, carrying fossils of Coal Measure type. The upper member, known as (3) the Morgan conglomerate, consists mainly, as its name indicates, of conglomerates, which are characterized by the local abundance of pebbles of limestone. It has an observed maximum thickness of 4500 feet, and in its upper portion resembles lithologically the Red Beds, generally assigned to the Trias.

The Juratrias, whose beds are separated from the last mentioned by a great unconformity, is represented by the Gunnison formation, which consists of a heavy white sandstone about 100 feet in thickness, overlain by shales and a little limestone, and carries a fresh-water fauna of supposed Jurassic age.

The Cretaceous is represented by five recognized subdivisions: The Dakota quartzite, 50–300 feet thick; the Benton shale, 150–300 feet thick; the Niobrara limestone, 100–200 feet thick; the Montana formation, comprising the Pierre shales and Fox Hills sandstones, 600–2000 feet thick; the prevailing lithologic characteristics of each of which is indicated by its name. Among later beds are the Ohio

formation, about 200 feet of sandstone and conglomerates; and the Ruby formation, with a maximum thickness of 2500 feet of sandstones, shales, and conglomerates made up to a large extent of eruptive débris. These formations are separated by an unconformity from the underlying Laramie, and to the west of this area pass beneath the beds of the Wasatch Eocene; in the absence of fossil evidence they have been classed as Cretaceous.

The geological structure of this region affords evidence of no less than four important orographic movements, involving the making of new land, the erosion and planing down of the same, and the inauguration of a new cycle of sedimentation, which account for the great variation in thickness of certain formations. First, during post-Archæan time, the first deposits, after which were Upper Cambrian (Sawatch quartzite); second, during Carboniferous time, followed by deposition of Weber shales and Maroon conglomerates; third, during Mesozoic time, followed by deposition of the Gunnison sandstone; and fourth, after Laramie time, followed by the Ohio, Ruby, and Eocene formations.

Mineral resources.—The most important economic product of the region is its coal, which is found in the lower part of the Laramie Cretaceous formation, between beds of sandstone. The quality of the coal varies, according to local conditions more or less favorable to metamorphism, from dry bituminous, through coking coal, to semi-anthracite and anthracite. Next in importance are its silver ores, which occur for the most part in true veins or fault fissures in all varieties of rock, but mainly in the sedimentary beds of upper horizons near eruptive rocks. The ores are generally rich, but in small bodies, and, in consequence of natural obstacles to cheap mining, have not been extensively worked. Gold has been found in paying quantities in the alluvium of a single gulch; lead and copper are accessory products in limited amounts.